HEALTH RISKS ASSOCIATED WITH SEWAGE EFFLUENT REUSE

CASE STUDY OF THE RIVERSIDE GOLF COURSE, TASMANIA

by

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submitted in partial fulfillment of the requirements for the degree of Master of Environmental Studies (by coursework)

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This thesis contains no material which has been accepted for the award of any other higher degree or graduate diploma in any tertiary institution and that, to the best of my knowledge contains no material previously published or written by another person, except when due reference is made in the text of the thesis.

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August, 1996

SUMMARY

This thesis conducts an international review of research regarding the public health risks associated with using municipal sewage treated effluent on publicly accessible land and provides an account of a case study that monitored the prevalence and persistence of faecal organisms irrigated onto a golf course.

It examines in detail the quantitative risk assessment process developed by risk managers in public health that is used as a tool to predict the likelihood of exposed groups of people to pathogens that may exist in the effluent. From the literature review, researchers have identified new waterborne pathogens that are resistant to conventional forms of disinfection, persist long enough in the environment to reach a potential human host and require only few in number to cause an infection. Relevant international and national wastewater reuse guidelines are also reviewed to highlight methods employed by risk managers to minimise the risks of infection as a consequence of wastewater reuse.

A comprehensive survey of current and proposed reuse schemes in Australia was also conducted to help ascertain the growth and the extent of reuse practices in the country. It was found that over the last 13 years the proportion set aside for intentional reuse of the total sewage volumes treated has almost doubled from 3.8 to 6.9% and will continue to grow in the near future. Most of this has been utilised for greenspace or agricultural irrigation where there will be some degree of public contact with the effluent.

Because of the current growth of reuse schemes and the prevalence of these new pathogens found in sewage it is prudent to conduct further environmental sampling for these high risk pathogens so that more informed risk assessments can be estimated.

A case study was conducted to identify persistence of faecal coliforms/*Escherichia coli* (FC/*E. coli*) pathways and persistence at the Riverside Golf Course, Launceston, Tasmania which uses chlorinated secondary treated sewage effluent supplied by the West Tamar Council for irrigation during warm dry weather (October 1995 - April 1996). The effluent is pumped to a temporary holding pond colonised by water fowl and is then spray-irrigated by pop-up sprinklers at a rate of approximately 5 mm for the fairways and 29 mm for the greens per week. Potential routes of transmission of FC/*E. coli* are discussed and a health risk assessment is presented.

Three rounds of FC/*E. coli* sampling were conducted on the 11-12/10/1995, 8-9/11/1995 and the 26-27/3/1996. Samples of the sewage treatment plant (STP) effluent and holding pond water were collected before and during irrigation. At 9 sites on the first five holes (fairways and greens) samples of the irrigant, creek water, turfgrass, topsoil, golf balls, players' hands and aerosols were collected before and after irrigation. Irrigant water, turfgrass and topsoil were sampled in the early morning; golf balls, players hands and aerosols in the morning, midday and afternoon; and creek samples in the afternoon. Samples were analysed using the membrane filtration technique with the exception of the aerosols which were collected onto agar strips using a high volume centrifugal sampler. Various meteorological, and physico-chemical parameters were also monitored.

It was found that the STP effluent entering the holding pond had low counts of FC ($\overline{x}$=14 cfu/100 mL, 95% range = 0 - 8 460 cfu/100 mL). The holding pond samples had considerably higher counts of FC/*E. coli* ($\overline{x}$ = 1 840 cfu/100 mL, 95% range = 372 - 9 120 cfu/100 mL) attributed to the birdlife present. The irrigant samples contained similar high levels of FC/*E. coli* ($\overline{x}$ = 945 cfu/100 mL, 95% range = 187 - 4 760 cfu/100 mL). Meaningful results of the levels of faecal coliforms on the turfgrass were only available for the third sampling round (Result Table 2.3). The mean value of FC/*E. coli* on turfgrass was 391 cfu/100 mL eq. (equivalent) after irrigation, which was significantly higher ($t_{1,16}$ = -2.027, P = 0.0386) than the value before irrigation, 75.2 cfu/100 mL eq., indicating that the practice of irrigation significantly increases the presence of FC/*E. coli* on the turfgrass. In contrast, the FC/*E. coli* counts were undetectable in almost all samples of soil, players' hands, golf balls and aerosols.

in almost all samples of soil, players' hands, golf balls and aerosols. Creek water samples bore several positive results but tended to be low and due to external contamination. The meteorological and physico-chemical analysis revealed a strong correlation between soil moisture and the presence of FC/*E. coli* in the soil.

Despite the fact that the holding pond faecal bacteria levels exceeded the Tasmanian Department of Environment and Land Management's (1994) *Guidelines for Re-use of Wastewater in Tasmania* mean limit of 750 FC/100 mL from five samples, dieoff was quite rapid indicating that this practice of wastewater reuse presents minimal health risks to golfers and groundstaff in terms of indicator FC/*E.coli* counts. However, it must be borne in mind that actual pathogens potentially present in effluent are not always adequately indicated by the faecal coliform group, especially viruses and protozoa which need further research as to their prevalence and persistence in the irrigated effluent. In addition, further research needs to be undertaken into the likelihood of the water fowl being a vector opportunity for disease with particular attention being paid to the increased risks associated with the potential disturbance of the holding pond sediment.

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S.D. Marrable

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GLOSSARY

Aetiology	The study of the causes of disease.
Activated carbon	Adsorptive carbon particles or granules which possess a high capacity to remove trace and soluble components from solution.
Biochemical oxygen demand (BOD)	A measure of the amount of oxygen used in the biochemical oxidation of organic matter, over a given time and temperature.
Coagulation	The aggregation of very small suspended particles (<0.1mm) into small visible particles (0.1–1mm) by adding a chemical coagulant.
Chlorination	The application of chlorine to wastewater effluent for the purposes of disinfection.
Disinfection	A process which destroys, inactivates or removes pathogenic microorganisms.
Dual Reticulation System	Two separate and distinct piping systems, one for transport of potable water and the other for transport of non-potable water.
Effluent	The water discharged following a wastewater treatment process
Epidemiology	The study of epidemics.
Faecal coliforms	Thermotolerant coliform organisms mainly indication faecal pollution. *Escherichia coli* is generally the dominant species.
Geometric mean, G_m	is calculated by taking the $1/n$ power of the product of n measurements, that is, $G_m = (n_1 \times n_2 \times n_3 \times \ldots . n_n)^{1/n}$ or $G_m = \log_{10}^{-1}(1/n \times [\log_{10} n_1 \times \log_{10} n_2 \times \ldots . \log_{10} n_n])$
Groundwater	Subsurface water form which wells or springs are fed.
Hazard	An environmental median where the presence of a deleterious substance may exist, such as microbial pathogens.

Indirect potable reuse	The derivation of potable water from surface or groundwater containing some proportion of treated wastewater.
Lagoon	Any large pond or holding used to treat wastewater by sedimentation and biological oxidation.
Median	The median value is the numerically middle value of a number of n measurements. Its main advantage over the geometric mean is that sample giving a zero result does not affect the result.
Membrane filtration	Techniques such as microfiltration, nanofiltration, and reverse osmosis used as a tertiary treatment process.
Open Access	Public access is permitted to areas where reclaimed water is in use.
Restricted Access	Public access is limited to specified times other than the period of effluent irrigation.
Potable Water	Water suitable for human consumption.
Reclaimed water	Water which has been derived from wastewater and treated to a standard suitable for an intended use.
Risk (actual)	The probability that an individual will develop a particular disease over a specified period when exposed to a particular hazard.
Risk (potential)	The chance that an infection of disease might occur which may not occur at present.
Sludge	The solids which are removed from wastewater by primary and secondary treatment.
SS	Suspended solids.
TSE	Treated Sewage Effluent
Turbidity	A condition in wastewater caused by the presence of suspended matter resulting in the scattering or absorption of light.

PART ONE

LITERATURE REVIEW OF WASTEWATER REUSE

CHAPTER 1

INTRODUCTION

Water! Of all the earthly substances, water alone is vital to all life forms. Its ability to dissolve, suspend, dilute, concentrate or distribute a wide range of materials makes it uniquely versatile and extremely useful. Despite its abundance on the face of the Earth, only a small amount is readily available for human consumption. The oceans contain 97.3% of the world's total water supply and a further 2.1% exists as ice or snow, leaving only 0.6% which is either underground or is fresh surface water that makes up the most of the world's lakes, rivers and streams. With only limited access to groundwater, melting ice and snow, this leaves a mere 0.014% readily available for human use (Nace 1967; Wiesner 1992: 233).

By the 21st century, human consumption of freshwater is expected to exceed supply. Already this has led to many political and ethnic conflicts over access to freshwater, particularly in arid nations. The Middle East and North Africa all face critical water shortages (McMichael 1993: 226). The Aral Sea in the former USSR is an example of a water mass shrinking at an alarming rate due to overconsumption (Wiesner 1992: 246; McMichael 1993: 228). In particular, shortages are increasingly becoming a problem in western industrial nations. McMichael (1992: 226) believes that modernity and rapidly growing urban populations have encouraged 'water hungry' lifestyles resulting in a ten-fold increase in freshwater use this century. Globally, agriculture and industry are the principal consumers of water (Figure 1.1). One-third of all food produced is now grown on irrigated land. In Australia and in the United States, 80% of available water is presently used for irrigation (Hayden 1993: 3, Watson 1994: 15). Despite efforts by some governments to conserve water, it has become increasingly scarce as industry and agriculture expand due to population growth particularly in arid regions in the western world (Schlafrig & Anderson 1992: 1). For example, in some parts of Australia and the United States, groundwater consumption is reaching or exceeding levels that natural recharge can supplement (UN ESCAP 1990: 50).[1]

[1] Australian's live on the second driest continent and yet are among the highest users of water per capita in the world (Conservation Council of Victoria 1993a: 1).

Global Water Use According to Human Activity, 1980 (in million m^3 per year)

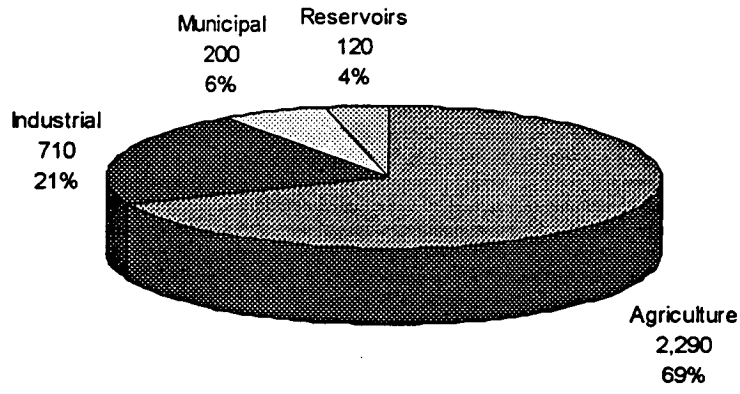

FIGURE 1.1

Source: Shiklomanov 1986

In the 1970's, UNICEF reported that a total of 1.2 billion people were without safe drinking water and this has since risen to 1.3 billion. UNICEF also reported that 1.6 billion were without any proper means of sewage disposal resulting in pollution of streams and rivers from which drinking water is drawn (Wiesner 1992: 240). As a direct result, 80% of the world's diseases are waterborne (Thorstensen 1994: 11). This is compounded by the increasing volumes of wastewater being discharged to inland and coastal waters due to the growth in water consumption. One notable example of this is the eutrophication in the Murray-Darling River basin as a result of excess nutrients from wastewater discharges (Davis & Gardner 1996: 12). Sewage entering the North Sea is also causing serious environmental concern for the European nations (Wiesner 1992: 240) and similarly, outfalls from major Australian cities have created the problem of beach pollution (Kueh & Grohmann 1989: 632).

As a result of such serious water management problems, the United Nations Economic and Social Commission for Asia and the Pacific report (UN ESCAP 1990: 49) has concluded that more attention must be paid by governments worldwide to encourage the development of wastewater reuse schemes, amongst other options, as a viable and vital water conservation and pollution control measure.

Despite the historical practice and the conservation value of wastewater reuse, concerns have been expressed over the health risks involved in its use. This thesis attempts to provide a comprehensive review of the health risks involved and to provide information of the persistence of pathogens based on an experiment conducted at a golf course that utilises treated sewage effluent (TSE) for turfgrass irrigation.

Wastewater reuse was a common form of waste disposal before the advent of modern engineered sewerage systems. Sewage provides a habitat for many pathogenic microorganisms and reuse enables another means by which they can infect humans. Diseases such as cholera, typhoid, amoebic and bacillary dysentery, and hepatitis have been well publicised waterborne causes of mass mortality that has been associated with fertilising soil with sewage. Infected individuals may show only mild, early or asymptomatic signs of an illness and yet they are capable of shedding large numbers of pathogens in sewage (Rowland & Cooper 1983: 34, Kowal et al. 1981: 277). By the start of the 20th century, developed nations had introduced engineered sanitation and provision of sewage treatment facilities that greatly reduced these high mortality rates and therefore resulted in the decline of the practice of recycling sewage (McMichael 1993: 264, 272).

Two major issues have recently refocussed attention onto the concern over the health risks of wastewater reuse. Firstly, because of the need to conserve water, reuse is experiencing a revival, particularly in developed nations, thus potentially increasing the degree of public exposure to pathogens in wastewater. Secondly, despite these modern advances in sewage treatment technology new microbes are emerging which are able to survive sewage treatment because of their capacity to resist disinfection. One such pathogen is *Cryptosporidium parvum* which has caused outbreaks of gastroenteritis recently in Britain and in the United States (Berkelman 1994: 272-74, Weinstein et al. 1993: 117 & Forsyth 1993: 14).

This thesis attempts to assess whether or not the health risks associated with effluent reuse can be effectively managed. Firstly, it presents a literature review of the risks involved with wastewater reuse and their management whilst focussing on current expertise within the field of health risk assessment. Secondly, it presents the results of a case study which monitored the movement and survival of faecal bacteria from a sewage treatment plant to and throughout a golf course. This case study involved a 6

month field survey which sought to provide data useful for assessing the health risks when irrigating sewage effluent on publicly accessible land. The Riverside Golf Course in Launceston, Tasmania, was selected as the test site where effluent from the local sewerage treatment plant has been used to irrigate the course since February 1994.

CHAPTER 2

RATIONALE AND SCOPE OF THE THESIS

2.1 Need for the Study

The impetus for the study came in response to two events: a public meeting in Sorell (Tasmania) to launch a wastewater reuse proposal on the 22nd of February, 1995, and a personal communication shortly afterwards with an ecologist working for Gutteridge, Haskins and Davey (GHD), Mr. Alan Sann, who was present at this meeting. The public meeting highlighted two points: health risks were an issue of concern to members of the public which cannot be ignored by councils seeking to promote such schemes and the importance of communicating accurately, honestly and confidently the actual health risks involved in wastewater reuse if public confidence is to be achieved.

Alan Sann (1995: pers. comm., 10 Mar.) expressed concern that the health risks associated with effluent reuse was an ill-defined area which needed further attention. In particular, he felt more work needed to be done on infectivity of pathogens present in the effluent and their pathways of infection. James Crook (1994: 54) also supports this thinking:

> The effects of physical parameters and chemical constituents are, for the most part well understood, and recommended criteria have been well established by the US Environmental Protection Agency (USEPA) and others. Health - related microbiological limits are more difficult to quantify, as evidenced by widely varying state standards and guidelines.

Minimal scientific work has been done in Australia to quantify the public health risks regarding effluent reuse and it is appropriate to do so as more municipal councils and private land holders are looking to use wastewater effluent for irrigation or other purposes. The associated health risks would appear to be worthy of further research and understanding. It is the purpose of this thesis to enable better management of the health risks in reclaimed water irrigation.

2.2 Aim of the Case Study

The case study specifically investigates the health risks to players and golf course personnel in contracting an infection from pathogens in sewage effluent used to irrigate the golf course. The investigation conducted extensive environmental sampling in order to identify potential faecal coliforms/*Escherichia coli* (FC/*E. coli*)

pathways and persistence throughout the golf course. From this information, the most likely paths of pathogen infection on the golf course are identified and the degree of risk associated with them is investigated. Results from the study are compared with the current state and national guidelines for wastewater reuse and secondary degree public contact guideline limits.

The thesis is divided up into two parts related to each aim.

- *Part One:* Is entitled *Literature review of wastewater reuse* and includes Chapters 1 through to 4.
- *Part Two:* Is entitled *Case study: Riverside golf course* and includes Chapters 5 through to 9.

2.3 Objectives of the Thesis

1. to conduct a literature survey on the current land based wastewater reuse schemes operating overseas and to collate a database of current schemes operating in Australia in order to ascertain the growth of the practice (Chapter 3);

2. to conduct a literature review on the process of health risk acceptance by exploring risk management practices and techniques for conducting a health risk assessment (Chapter 4, Sections 4.1–4.3);

3. to review and critique the various Australian state, national and international guidelines relating to wastewater reuse (Chapter 4, Section 4.4);

4. to determine the persistence and distribution of FC/*E. coli* in effluent used to irrigate a golf course in the summer season. Chapters 5, 6, 7 and 8 present the background, methodology, results and discussion of the experimental case study respectively;

5. to identify any correlations between persistence of faecal microorganisms, specific water quality and bioclimatological parameters including pH, temperature, conductivity, wind speed and direction, soil moisture and rainfall (Chapters 7 and 8); and

6. to undertake a human health risk assessment for different types of exposure to wastewater used on the golf course, that is, by inhalation and accidental ingestion (Chapter 8).

2.4 Scope and Limitations of the Study

Although discussion is made regarding all the different forms of wastewater reuse in the world, the human health concerns addressed in this thesis specifically refer to publicly accessible areas that are effluent irrigated in temperate climates.

Review and presentation of an Australia-wide database of current reuse schemes (Chapter 3), whilst it is not comprehensive, is based on information provided by and available to the relevant state regulatory authorities.

No epidemiological study or investigations of causes of infectivity in golfers was undertaken because of the cost and difficulty of obtaining reliable and accurate information. Other sources of epidemiological evidence on effluent reuse are discussed in the literature review (Chapter 4).

2.5 Methodology of the Literature Review

Material used for the literature review in Chapters 3 & 4 were obtained as follows:

1. Initially, CD-ROM searches were conducted using the University of Tasmania Library CD-ROM databases. This included the Life Sciences, MEDLINE, Applied Science and Technology, Heritage and Environment, and Streamline Collections. Abstracts of relevant papers were obtained after performing key word searches. References were obtained by students within the Department on related subjects. Conference proceedings were also obtain from students or from the University libraries. Key word searches were also conducted on the university's catalogue system and library reference booklets were used to located relevant serials and monologues. If an important article was in a serial not kept at the University, Tasmanian Government Libraries, such as, the State library, the Department of Environment and Land Management Library and the Department of Health and Community Services Library were visited. Failing this, articles were obtained by interlibrary loans from mainland university libraries.

2. Time was spent reading through the recent few years of each relevant serial held at the university libraries to locate other relevant articles.

3. Material was obtained by attending two conferences. The first provided internationally recognised material on health risk assessment entitled, 'Human Health Risk Assessment' conducted by John Evans from the Havard School of Public Health, Massachusetts, as part of the International Winter Environment School, 1995, Gold Coast, 26-30th of June, organised by the University of Queensland, the Australian Water and Wastewater Association and the Institute of Chemical Engineers, Australia. The second conference was more specifically geared to wastewater reuse issues entitled the 'WaterTECH' conference held at Darling Harbour Sydney, 27-28th of May, 1996, organised by the Australian Water and Wastewater Association. The particular stream I attended was 'Water Reclamation and Reuse'. Keynote speakers were Prof. George Tchobanoglous of the University of California who addressed the issue of appropriate technologies for wastewater reuse and Dr Charles Gerba, from the University of Arizona who presented a talk entitled, 'Quantitative Microbial Risk Assessment for Reclaimed Wastewater'.

4. Australian guidelines and regulations of wastewater reuse and details of reuse schemes operating in Australia were obtained by contacting the relevant authorities in each state and by contacting federal agencies such as the National Health and Medical Research Council, the National Environment Protection Agency and the Urban Water Research Association of Australia.

5. Dr Gary Grohmann, a virologist at the University of Sydney, visited Tasmania at the invitation of my supervisor who accompanied us to the golf course at Riverside and provided some helpful advice. In addition, I attended several talks he gave regarding environmental health risks of effluent reuse and environmental microbial sampling techniques.

In all, over 200 references were collected. Due to time constraints it has not been possible to use all the information so judgment was exercised as to which references to cite.

Often information used was from a secondary source. Where this occurred, as much as possible, the primary reference was obtained but because of the frequency of citing other works and difficulties in obtaining the original, secondary references are made with the acknowledgment that misinterpretations are possible. These secondary references are noted by 'as cited in ....' at the end of the reference.

CHAPTER 3

HISTORICAL REVIEW OF WASTEWATER REUSE SCHEMES

3.1 Benefits and Uses of Domestic Wastewater

The concept of recycling sewage effluent and sludge is not new. The benefits of applying human waste to land has long been recognised as a strategy for water conservation, ameliorating contamination in the environment and making use of the nutrient content in the effluent. In 1863, von Liebig in 'The Natural Laws of Husbandry', (Jewell and Seabrook 1979) wrote:

> Even the most ignorant peasant is quite aware that the rain falling upon his dung-heap washes away a great many silver dollars, and that it would be much more profitable to him to have on his fields what now poisons the air of his house and the streets of the village; but he looks on unconcerned and leaves matters to take their course, because they have always gone on in the same way.

Von Liebig stressed that even for the sake of financial gain, it is essential to feed back nutrients contained in sewage which originally came from the land. Indeed 'recycling' is fundamental to the laws of nature, without which all life would cease to exist. In most parts of the world, cultivable land requires on average 250 mm rainfall annually. This requirement can be met for every hectare by 35 persons each producing 200 L of sewage per day (Müller 1969: 22). However, with the advent over the last 100 years of modern medicine and hygienic practices, and a Western-mentality of 'once through use and dispose', many of the advantages of reusing domestic wastewater were not promoted in an understandable attempt to keep potable water sources clearly separate from sewage treatment and discharge (Schlafrig and Anderson 1992: 1).

Therefore, in modern day society, that which is profitable, not just for humans but also for the environment, has been literally going down the drain and is eventually discharged to the world's rivers and oceans. Nevertheless, with the increasing pressure being placed on limited freshwater supplies due to increasing urban populations in arid regions (Cort 1987: 34, 44), an impetus has emerged to relearn the lessons of nature by seeking to establish 'new' solutions, to conserve and recycle natural elements. California, for example, is preparing itself for annual water shortages of 4.6–7.0 billion cubic meters by the year 2020 AD and the public is becoming more reticent to pay for new supply facilities (Pinholster 1995: 174A). Even

in rural areas, impending shortages of potable water and expanding agricultural production, combined with a desire to economise on fertiliser costs, have prompted water resource planners to reconsider rural reuse schemes.

Water planners have come to realize in the last 20 years that the multiple advantages of water conservation, nutrient recycling and pollution minimisation of surface and groundwaters bestowed by recycling effluent, need to be considered (Cort 1987: 34). A Committee on Water Quality Criteria of the National Academy of Sciences-National Academy of Engineering in 1972 (Kowal et al. 1981: 271) recognised the potential growth of wastewater irrigation of crops because it meets both the need for new sources of irrigation as well as the need to reduce pollution of waterways. In addition, the US General Accounting Office in 1978 (Kowal et al. 1981: 272) saw that aquifer recharge in particular would satisfy dual needs of providing higher treatment of secondary treated effluent and the recharging of groundwaters. Concurrently, there is also a growing awareness in Australia that organic matter must be returned to the soil to maintain its structure and fertility (Bowmer & Laut 1992: 202).

In 1987 during a prolonged drought in the USA, the proceedings of the Water Reuse Symposium IV (American Water Works Association 1988) held in Denver, Colorado, clearly explained that wastewater reuse is technically and economically feasible. In terms of significant trends for wastewater reuse in the future, one speaker at the Symposium (Westerhoff 1987: 18) predicted that the following factors were likely to accelerate the growth of wastewater schemes: the need to conserve water for potable reuse; diminishing concerns over health effects; the rising costs of drinking water; increasing public acceptance of reuse; and, upgrading of sewage treatment technologies. Newnham (1992: 8) feels that significant progress in this area has been made already, although there still is a considerable resistance to change by regulatory authorities.

Wastewater has an important role to play in the area of resource management for it can be used in some cases as a suitable substitute for fresh water or for augmenting depleted inland waterways. Nevertheless, organic matter and other chemical compounds in wastewater can severely pollute the environment if discharged in excessive amounts. Heavy metals in wastewater can enter the food chain by being absorbed by aquatic plants and bottom feeding molluscs. Organic toxicants present in wastewater can poison living organisms and can accumulate in living tissue causing

genetic and reproductive abnormalities (Conservation Council of Victoria 1993A: 7). The discharge of nitrogen and phosphorus into an aquatic environment have led to undesirable aquatic growth and can disrupt the balance of aquatic ecosystems (Davis and Gardner 1996: 12; Conservation Council of Victoria 1993a: 7). However, nitrogen and phosphorus can be used effectively as nutrients for crops, 'greenspaces' and in fish ponds (WHO 1989: 10, 13; GHD 1983: 8).

Water reuse projects are being implemented for many reasons (Crook 1994: 55; Crook & Okun 1987: 237):

- Opportunity - where potential users are located close to a sewage treatment plant which provides a reliable and cheap water supply, as is the case with Riverside Golf Course, Launceston;
- Need - it may be the only cost-effective option in restricted water use areas;
- Conservation - using wastewater for irrigation can allow for redirection of freshwater to other uses;
- Reliability of supply;
- Where well-established technology exists;
- Economics - the producer may save on operational costs by selling the effluent and the user will benefit when purchase cost is less than current rates for potable water;
- Pollution abatement - the effect of reclaimed water that would otherwise be discharged into the environment as a pollutant, can be minimised by reuse;
- Public policy - elected officials are becoming more active in promoting reuse, particularly in restricted water supply areas. Regulatory authorities on all levels are also mandating its use where feasible and cost-effective; and
- Successful experience - pilot and research studies have provided useful and encouraging information. There are hundreds of schemes currently operating in the US which enjoy enthusiastic public acceptance.

3.2 Types of Wastewater Reuse Schemes

The various types of wastewater reuse schemes currently employed are listed below with examples in order of increasing degree of potential human contact with treated effluent.

3.2.1 Silviculture Reuse

Silviculture is the intensive cultivation of trees as a wood resource. The irrigation of plantations with wastewater has a number of advantages over other methods of reuse. The need for expensive pre-treatment and disinfection can largely be avoided without an increase in health risks to the public (Cromer 1980: 87). The wastewater usually receives primary[1] treatment only. Hence most of these types of irrigation schemes are restricted from public access at all times. When young, the trees require higher volumes of water than do other crops but require less maintenance. They also filter out heavy metals from the food chain (Myers et al. 1992: 2). Reuse of effluent as opposed to conventional irrigation has also contributed to significant increases in tree growth rates (Myers et al. 1992: 1).

The use of wastewater in silviculture can also bring considerable environmental benefits to the surroundings of large cities, particularly in areas that suffer deforestation due to fuel wood demands. Tree belts serve also to stabilise deserts around cities and control dust storms (WHO 1989: 17).

3.2.2 Industrial Reuse

Wastewater can also be used for industrial processing, cooling, construction, mining and a wide range of cleansing operations (Okun 1990). Water is an ideal cooling agent, having a higher heat capacity than most other volatile liquids (Weisner 1992: 238). The oldest and possibly the largest example is the use of effluent for process and cooling water by the Bethlehem Steel Corporation in Baltimore (Crook & Okun 1987: 239). Industrial cooling processes using TSE (Treated Sewage Effluent) have been operating in plants in the USA, England and South Africa since the 1940s and 1950s (Wijesinghe 1992: 3).

3.2.3 Aquaculture Reuse

In medieval Europe, fish and large aquatic plants were fertilized with human wastes (WHO 1989: 12). This is still practiced today in many parts of Asia, Germany and

[1] For definition of primary, secondary and tertiary treatment see Section 4.3.2.4

Hungary. Calcutta has the largest wastewater-fed aquaculture system in the world covering 12 000 ha. Reduction of total coliforms in the fish-ponds in Calcutta is reported to be substantial and the practice of thoroughly cooking the fish before eating ensures a low potential health risk (WHO 1989: 24).

3.2.4 Agricultural Reuse

Wastewater reuse in agriculture is the most common form of reuse and has gained wide acceptance throughout the world (Tchobanoglous 1996: 247). As mentioned in Chapter 1, agricultural irrigation is the largest consumer of water and is placing tremendous pressure on local supplies in many areas. Thus this practice is already ameliorating this pressure as well as minimising the need for fertilisers by recycling nutrients (Shahalam & Mansour 1989: 148). According to the Conservation Council of Victoria (1993a: 6), 'It has been estimated that the "fertiliser value" of Melbourne's effluent alone is around $10 million annually'.

3.2.5 Landscape 'Greenspace' Reuse

This involves application of TSE on sports grounds, golf courses, parks, nature areas, highway medians and border strips, and airport border strips. Fixed or mobile sprinkler systems may be used. Effluent may be applied to greenspaces at rates of 12 to 25 mm per week {600–1 200 mm per year} (GHD 1983: 11).

Irrigating turfgrass with reclaimed water has become increasingly attractive, especially in highly populated areas experiencing water shortages and rising costs in potable water supply (Harivandi 1994: 106). Golf courses are by far the major recreational turfgrass users of water. They intensively manage turf, necessitating large and consistent volumes of water (Watson 1994: 19; Mancino & Pepper, 1994: 174). Successful effluent irrigation of turfgrass has led to the use of effluent on many prestigious courses in Arizona, California and Florida. The usually permeable soils, along with high shoot and root density of turfgrass, provide a cleansing (filtering) function for the water before it percolates into the ground as well as uptaking nutrient in the effluent. In addition, most expanses of irrigated turf are in urban areas where effluent is readily available. The US Golf Association and the American Society of Golf Course Architects (1994) listed 230 golf clubs currently using wastewater for irrigation.

3.2.6 Residential Non-potable Reuse

Residential non-potable reuse has applications for garden watering, car washing, toilet flushing and fire fighting. A scheme like this requires two separate and individually marked reticulation systems; one for potable use and one for non-potable reuse, so called 'dual reticulation systems'. Plumbing standards specify measures to ensure no cross-connections or cross contamination between systems. The treatment required for residential non-potable reuse in the USA usually requires secondary treatment followed by coagulation, filtration and chlorination (Crook & Okun 1987: 240).

In the United States, Grand Canyon Village, Arizona, has been using recycled effluent since 1926 for toilet flushing. Schemes also began in Colorado Springs, Colorado, in 1960, Irvine Ranch, California, in 1975 and in St. Petersburg, Florida, in 1977 (Crook & Okun 1987: 240). Effluent for toilet flushing in large buildings is being implemented in Japan and in Singapore, a 12-story multi-housing housing complex of 25 000 people also uses reclaimed water for toilet flushing (Okun 1991). In Australia, the NSW Recycled Water Coordination Committee has released guidelines for non-potable residential reuse and a residential reuse scheme is underway for a new development in Rouse-Hill, Sydney, with the effluent microbial quality being specified as for drinking water (Fisher 1992).

3.2.7 Indirect Potable Reuse or Aquifer Recharge

Reclaimed water is used in several countries to artificially recharge groundwater aquifers which are over utilised as a potable water supply. There are two types of artificial recharge: surface infiltration and direct injection. Surface infiltration involves spreading the effluent over an enclosed area of land that has a particular quality of soil that filters out pollutants and microorganisms before it percolates to the aquifer. The wastewater is usually pretreated and then applied to land at a rate between 0.6 to 6 m/annum by using either sprinklers, surface flooding or ridge and furrow techniques. Soils are usually medium to fine textured with moderate permeability. Surface vegetation can include pastures, forests, lawns, golf courses and crops (Kowal et al. 1981: 272).

Direct injection bypasses the soil by introducing the effluent into the aquifer by means of a drilled bore. The wastewater has to be of a higher quality than that for surface infiltration methods (Pinholster 1995: 177A) because the effluent is not pretreated by the soil. Examples of this are found in California, Florida and Israel (Cort 1987: 36;

Newnham 1993: 4). Notably, indirect reuse occurs unnoticed almost everywhere in situations where water is extracted from rivers which receive wastewater effluent further upstream.

3.2.8 Direct Potable Reuse

These schemes purify sewage effluent to a point where the finished product is of a quality which is equal or superior to locally available raw water supplies (Western Consortium for Public Health 1992). These plants tend to be found in extremely arid areas, like Windhoek, Namibia, where a potable reuse plant has augmented drinking water supplies since 1968 (van der Merwe 1996: 327). Typically, these plants demand many stages and backups in the treatment train and require very stringent regulation making such a plant expensive to run (Nichols 1988: 1932).

Another example is an $18 million, 3.8 ML[2]/day , direct potable water reuse demonstration project located in Denver, Colorado, which directly converts unchlorinated, secondary treated wastewater into drinking water (Lauer 1992; Public Works 1992). Pending public acceptance, Sydney Water is also planning a 5 ML/d potable reuse schemes in the Hawkesbury Nepean catchment. A demonstration plant that mixes St. Mary's STP effluent with potable water will be operational by 1997 (Fink 1996: 374; Perc Wyles 1995, pers. comm., 11 July).

3.3 Environmental and Economic Management of Wastewater Reuse

Dr. David Leece (1992), Director of the Water and Natural Resources Branch of the NSW EPA, stated that any successful scheme must adopt 'Best Management Practices' and should be ecologically sustainable. A reuse scheme must assess the presence of nitrogen, phosphorous and particularly salt concentrations in the effluent for their ongoing impacts on the type of soil and crop to be irrigated. The amount of effluent applied must be balanced with the uptake of the crop, rainfall and evapotranspiration rate to ensure no excess runoff, groundwater contamination, water logging, salinity and alkalinity problems occur (GHD 1983: 9). Chemical components found in effluent, such as, (Harivandi 1994: 107) sodium, potassium, magnesium, chloride, bicarbonate, sulfate, boron, copper, iron, manganese, molybdenum and zinc are plant micronutrients that need to be applied to crops in the right amounts.

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[2] 1 ML = 1 million litres, 1 000 ML = 1 GL, 1 000 GL = 1 cubic kilometer.

Studies have shown that, with proper management, crop yields may be increased with secondary treated effluent irrigation. Typical concentrations of 15 mg/L of total nitrogen and 3 mg/L of phosphorus in a 2 m column of irrigant applied per annum in arid areas can substantially reduce or eliminate the need for fertilisers (WHO 1989: 17). The organic content also acts as a soil conditioner increasing the capacity of the soil to store water. Microorganisms in the sewage can also contribute to soil fertility by recycling organic matter. Typical concentrations of nitrogen (N) or phosphorus (P) in Australian wastewater are 15–128 mg/L and 0.5–45 mg/L respectively (Sandford 1977).

Overapplication can result in groundwater contamination with the accumulation of nitrate in the soil. This is particularly so when the groundwater aquifer is close to the surface or the unsaturated zone is highly porous. Standing pools must also be avoided to stop the breeding of mosquitoes which are vectors of disease. Some chemicals which are toxic to animal and plant life may also be of concern. For example heavy metals or salts may accumulate in soil and reduce crop yields. Usually, municipal wastewater has low levels of heavy metals if industrial discharges to sewers are adequately pretreated (WHO 1989: 18). Many species of plants are intolerant to sodium chloride and an excess of boron is particularly toxic.

In regard to turfgrass irrigation of golf courses, effluent quality is of prime importance for successful turfgrass management. Plant-soil-water relations and the chemical and physical properties of the soil play a very important role (Harivandi 1994: 106). In particular, turfgrass can be harmed by excess sodium, ammonium-nitrogen, salinity and trace elements.

The economics of wastewater reuse schemes will vary greatly from facility to facility depending on the level of foresight, investigation and planning. Wastewater can often be a very costly water source and indications have been that some wastewater reuse schemes have been more costly in economic terms than using available potable supplies. This is particularly so when extensive infrastructure needs to be installed. Warrick Battye-Smith, sewage engineer of Coffs Harbour City Council, commented on the inherent pitfall of enthusiastically promoting reuse without carefully considering that reclaiming water costs time, energy and money (Battye-Smith 1992: 1, 5). The actual costs of reclaimed water may well be more expensive where potable water is relatively cheap. Figures in the USA indicated that the cost of supplying effluent may

range from $98 US per ha-m to as high as $7 300 US per ha-m (Mancino & Pepper 1994: 174).

3.4 Historical Overview of Worldwide Usage of Wastewater

Wastewater reuse developed alongside urban sewerage systems introduced during the nineteenth century and were primarily agricultural in function. Schemes were developed in Australia, France, Germany, India, the United Kingdom and the USA in the latter part of the 19th century and in Mexico at the turn of the century. However, these schemes became unfeasible in temperate regions when the volumes of sewage from expanding urban areas required greater amounts of land, which in turn became decreasingly available. Only Australia (Werribee sewage farm), India, West Germany and Mexico continued to use water in this way (WHO 1989: 10).

Today, thousands of schemes are in existence which range in size from a few hectares up into the thousands. In India, for example, several hundred reuse schemes serve an area of 73 000 ha. The majority use raw wastewater or minimally treated wastewater and do not provide adequate health protection measures (WHO 1989: 21).

Reuse of treated wastewater for crops and urban greenspaces has grown significantly in Australia, Latin America, North Africa, Spain, other Mediterranean countries and the USA. In the USA, effluent has been applied to golf courses since the 1960s particularly in California and Arizona where water restriction laws apply. It has been popular with the general public and among state and local agencies because of its conservation value (Gill & Rainville 1994: 44). Yet the use of the effluent has had varying degrees of impact resulting in golf course architects having mixed feelings about the product. In Canada, since 1983, 79 municipalities have been applying domestic effluent on land mostly in semi-arid regions (Environment Canada 1984).

In the United States, the potential for recycling wastewater to reduce demand on existing water supplies is significant when one considers the volume of sewage it generates a year. In 1988, the USA was producing 117 000 ML (around 62 000 olympic swimming pools) of wastewater a day (Solley et al. 1988).

Historically, non-potable reuse projects were local initiatives with little support from regulators or water supply managers. They were located close to the sewage treatment plant (STP). Now STPs are being purpose designed and built to provide a reuse option

(Crook & Okun 1987: 237). Non-potable reuse is becoming widely practiced in water deficient regions of the USA such as, California, Florida, Arizona, Texas and Colorado and tends to be for high volume users. In California and Texas the use of reclaimed water for irrigation is mandated by law. This has resulted in the dramatic increase of wastewater reuse schemes. In 1972, there were 571 municipal land treatment systems in the US. In 1980-81, 1 180 schemes were operating whilst over 3 400 were being implemented (WHO 1989: 21; Crites 1984: 141A). By 1992, 1 900 reuse schemes were operating in 34 states (USEPA 1992: 123).

In California, during the 1980s, wastewater reuse grew by approximately 20% (Crook & Okun 1987: 238). In 1988, it was estimated by the Department of Water Resources that 430 000 ML per year of municipal wastewater was being reclaimed involving approximately 500 reuse schemes with urban reuse accounting for 115 of these schemes. The volume reused was also predicted to double by the year 2010 (Cort 1987: 34; Nichols 1988: 1932–3). In 1992, American City & County (1992: 56) reported that in the arid state of California ranchers were embracing the idea of wastewater reuse for permanent crops and pasture land. As ranchers experienced increases in cattle numbers and milk production as a result of wastewater reuse the demand for effluent began to outstrip supply. Grape growers and nurseries also competed for the product.

In Florida, 26% of the total wastewater flow was being reused by 1990. This involved 200 reuse schemes utilising 1 000 ML/d (FDER 1990). The types of schemes included: greenspace irrigation; agricultural irrigation; industrial reuse; and residential dual reticulation systems. Project Apricot, is one such example of a residential reuse program in the City of Altamonte Springs. The scheme aimed to make recycled water available to all properties within the City of 40 000 by the year 1995 (Boyd, 1992: 1-2).

Formal research in the USA concerning the use of municipal wastewater and sludge on land began to take place in the late 1960s (Crites 1984: 140A). Initially the dominant philosophy was to view discharge of wastewater onto land as a method of disposal rather than as a recycling option. Deeper understanding of the ability of soil systems to not only treat wastewater but to utilise its nutrient content has reaffirmed the resource value of wastewater.

In addition to California and Texas, arid nations, such as, Israel, Jordan, Peru and Saudi Arabia have mandated the reuse of all STP effluent for crop irrigation (WHO

1989: 10). Saudi Arabia, in particular, seeks to ensure that by the year 2000, 20% of its water supply for agriculture will be from reclaimed water (Al-Mutaz 1989).

In Israel, 70% of the total urban wastewater flow is used for 250 irrigation projects. Large-scale reuse of sewage effluent was initiated in 1972 by the government. In small municipalities, treatment mainly involves an oxidation pond whereas the larger towns have mechanical treatment systems where the effluent is first stored and then applied to crops (Avnimelech 1993: 1278). The high level of farming education and treatment in stabilisation ponds for use with mainly cotton and fodder has ensured a successful health protection strategy (WHO 1989: 23).

In Amman (Jordan), Tunis (Tunisia) and Lima (Peru) wastewater treated in stabilisation ponds is used to irrigate maize, vegetables and fodder crops. In Ica (Peru), wastewater is used to irrigate 400 ha of cotton, maize and grapes. Secondary treated effluent without chlorination is used to irrigate several thousand hectares of citrus trees in Tunisia. The wastewater is distributed through buried pipes thus providing good health protection for workers (WHO 1989: 22).

In Mexico, most of the sewage from Mexico City which produces 4 750 ML/d is used to irrigate 80 000 ha for the production of alfalfa, maize, barley and oats, making this the largest reuse scheme in the world. No conventional (mechanical) treatment of the sewage occurs, although some form of natural treatment may occur as the sewage travels 60 km in open channels, as it is held in seasonal storage and when it is diluted with river water (WHO 1989: 21). Enforced crop restriction is the only health measure. It has been operating for the past 30 years and it is claimed that the consumer's health has been adequately protected.

In regard to the future of wastewater reuse schemes, at the AWWA 15th Federal Convention in Queensland, the keynote speaker, Professor Tchobanoglous, envisaged that reuse of effluent would continue and the re-design of collection and treatment systems would take place in order to enhance its availability (Swinton 1993: 16). Reuse schemes need not be limited by size or by location which allows them to be operated in remote and small communities. Innovative small decentralised sewage treatment systems which can have an effluent recycling function are becoming popular in places where centralised sewerage systems are not feasible in the near future. They can treat

effluent to the same degree as centralised systems and provide long-term solutions for environmental management (Tchobanoglous 1996: 247-48).

3.5 Historical Overview of Wastewater Usage in Australia

Recycling of treated effluent is a developing concept for Australia. Up until about 20 years ago, the reuse of effluent in Australia was largely viewed as a land based disposal of an unwanted waste. There was minimal planning and detailed design. In the early 1980s, GHD Pty Ltd (1983) conducted a detailed survey on behalf of the Commonwealth Government on the quantities and purposes for which effluent was used on a state by state basis. It reported that the total sewage flow in Australia amounted to around 1 300 GL/a and only 4.4% (56 GL/a) of the treated effluent was reused with a summer peak of up to 7-8% (GHD 1983: 16; 1991). If Melbourne's Werribee sewage farm is included, these reuse figures are inflated to about 11% (146 GL/a) of the total annual sewage flow with a summer peak flow of 20% (GHD 1983: 31). Victoria was the greatest user of effluent whilst NSW and WA were the second and third highest users respectively. Surprisingly, the highest users per capita are the Western Australian country areas with a high per capita use predicted in the NT.

Numerous Australian country towns had been using reclaimed water for many years for such uses as park and oval watering, ornamental garden watering, dust suppression on roads and for various industrial applications (Battye-Smith 1992: 2). Industrial reuse of wastewater has been low in Australia, partly due to economics. Nevertheless, the potential exists since power generation and cooling in general consumes large quantities of water in evaporation processes. Various silviculture trials have taken place in Australia over the last 20 years to establish the viability of trees irrigated with effluent. A major research effort has been carried out by the Victorian Forestry Commission which has a number of experimental plantations throughout the state. The Melbourne and Metropolitan Board of Works (MMBW) had trial plots in Victoria and the CSIRO also had trial plots in Victoria, Darwin and Beenyup in Western Australia (GHD 1983: 9).

The GHD report (1983: 32) concluded that there was very little reuse in Australia when considering the limitations of potable water supplies, the reliability and the close proximity of STPs to urban centres. They list several possible reasons for this:

- the lack of information as to health and environmental effects;
- the lack of firm guidelines for reuse;

- the lack of joint planning between sewerage and water schemes;
- the lack of interest and acceptance by users, water managers and the public;
- potable water has been available more cheaply than treated wastewater (GHD 1991); and significantly,
- the major population areas are centred on regions having high enough rainfall to supply sufficient potable water.

Possible forms of effluent reuse that could be exploited in Australia were identified by GHD (1983: xi) as:

- industrial use, particularly for industrial cooling;
- irrigation, including agriculture, silviculture and landscape watering;
- water conservation, such as aquifer recharge and streamflow maintenance and flushing of inland waterways;
- municipal purposes such as recreational lakes, fire fighting, saleyard flushing, domestic gardens, toilet flushing, car washing; and,
- potable water supply.

Today, both federal and state governments are promoting wastewater reuse (Schlafrig & Anderson 1992: 1) particularly in view of the recent attention focused on the cumulative nutrient loads discharged to inland waters in the Murray-Darling and the Hawkesbury-Nepean catchments (GHD 1991). Dr. David Leece (1992), of the NSW EPA, stated that the EPA encourages the reuse of domestic wastewater and its use as a potentially valuable resource. He notes that traditional land application of wastewater in rural NSW over a century has been a cheap method of disposal that often exceeded the land's assimilative capacity. The NSW EPA has encouraged a transition in thinking, that is from 'disposal' of a waste to 'reclaiming' a resource, and they now prefer land application of wastewater with a 'best environmental outcome' in view. This change of thinking has reflected current opinion in the USA (Newnham 1992: 2).

Several Australian water agencies and regulating authorities are now adopting a 'no discharge' policy and are producing new and more stringent water quality guidelines (ANZECC 1992) which place greater emphasis on the need to remove nutrients before disposal into waterways, or alternatively redirecting effluent for application on land (Bowmer & Laut 1992: 201, 205).

More recently, research in the area of effluent reuse has been undertaken by Universities and water authorities across the country. The University of Adelaide has trialed the growth of salt-tolerant hardwood species in a 400 ha forest at Two Wells using effluent as a feasibility study. The trials have shown that most tree species respond markedly well to irrigation with effluent. In addition, a hardwood treelot trial commenced in 1990 in South Australia demonstrating that *Eucalyptus globulus* performed particularly well on marginal soils in a semi-arid climate (Boardman et al. 1996: 291). The Centre for Wastewater Treatment at the University of NSW is conducting trials to investigate viable opportunities for using TSE in cooling towers (Wijesinghe et al. 1992: 1) as well as studying the effects of effluent reuse on soils and groundwater (Wagga Wagga). They have also conducted trials in conjunction with the Sydney Water Board on domestic garden watering with TSE in Shoalhaven. The University of Queensland has been conducting research on potable reuse (Swinton 1990). Tests in recharging of aquifers by surface spreading of secondary treated effluent have also been carried out in Western Australia (Brown at al. 1983: 19).

Computer programs are also being developed to assist individual industry managers and regulatory authorities design economically and environmentally sustainable reuse schemes. MEDLI - Model for Effluent Disposal using Land Irrigation is one such program produced by the CRC for Waste Management and Pollution Control Ltd and the Queensland Department of Primary Industries (Davis & Gardner 1996: 12) which predicts the fate of the effluent, its nutrients, salts, volatile solids and hopefully, the more difficult to predict, pathogens.

In total, Australians consume 13 544 GL/a, equating to 2 200 L per person per day of water and thus generate 1 672 GL/a of sewage (AWWA 1996a: 46). Urban water consumption averages 480 L of water per person per day which results in approximately 260 L of wastewater per person per day. The metropolitan areas produce 71% of the sewage (1 179 GL/a) whilst, significantly, 70% of the total water supply (10 200 GL/a) is used for rural agriculture irrigation (Hayden 1993: 3; AWWA 1996a: 38, 46). From these figures and from the geographical disparity between the potential supplier and the user, reuse cannot hope to totally replace the need for other sources of water for irrigation. Nevertheless, for much of the inland areas the availability of groundwater is critical where it is a primary water source and in major urban centres that are continuing to grow, supply charges for potable water may increase due to pressures on supply. This necessitates the search for new water

supplies that are increasingly difficult to locate. Therefore creative ways for recycling as much of the sewage effluent as possible is needed to offset these pressures.

John Anderson (1996: 1), Chairman of the NSW Recycled Water Coordination Committee, estimates that currently 12% of the total municipal sewage effluent is recycled in some form. Half of this, 6.2% is directly reused, amounting to 90 090 ML/a (compare with result in Table 3.1). The remainder is indirectly reused where water is drawn downstream from a STP discharge point in an inland watercourse. Anderson (1996: 3) predicts direct municipal reuse will grow to 200 000 ML/a by the year 2000AD. However, Anderson (1996: 4) estimates the actual contribution of recycled effluent to the total urban water demand is less than 2%. In addition, when comparing the current percentage reuse of wastewater figure of 12%, with the equivalent 1983 figure of 11%, it is evident that effluent reuse has only grown in step with increasing national sewage flows since these values are essentially the same. It will be important to note whether or not the percentage figure will increase at a greater rate in the future.

TABLE 3.1 - Reuse schemes operating in Australia

Table 3.1 lists current reuse schemes operating in Australia. The units of volumes reused are standardised to ML/a for each scheme. Original data quoted in ML/d as shown in brackets in the table are adjusted by a factor of 365 days if the scheme is continuous (i.e. industrial) and a factor of 365/3 days for the schemes likely to operate during the summer months only (i.e. greenspace and agricultural irrigation). The information used to compile the data is based on reports, reviews, articles and available statistics supplied by relevant state authorities:

State	Location	Type of Scheme	Volume ML/a	Status	Reference
NSW	Armidale	Pasture	300	Current	NSW DLWC[a] 1996
	Bega	Golf courses	200	Current	NSW DLWC 1996
	Bega	Pasture	50	Current	NSW DLWC 1996
	Bingara	STP grounds	2	Current	NSW DLWC 1996
	Bingara	Treatment works operation	8	Current	NSW DLWC 1996
	Bland (West Wyalong)	STP grounds	18	Current	NSW DLWC 1996
	Bland	Golf courses	18	Current	NSW DLWC 1996
	Bland	Playing fields	175	Current	NSW DLWC 1996
	Bourke	Irrigation	250	Current	NSW DLWC 1996
	Broken Bay	Playing fields	-	Current	GHD[a] 1983: 18
	Broken Hill	Landscape and dust suppression	1 825 (5 ML/d)	Current	GHD 1983: 17
	Cobar	Golf course and playing fields	97	Current	NSW DLWC 1996
	Coolah	Golf courses	-	Current	NSW DLWC 1996
	Coffs Harbour	Golf courses	20	Current	NSW DLWC 1996
	Coffs Harbour	Playing fields	10	Current	NSW DLWC 1996
	Coffs Harbour	Airport	37	Current	NSW DLWC 1996
	Coffs Harbour	Stadium	36	Current	NSW DLWC 1996
	Coffs Harbour	Public lawns	12	Current	NSW DLWC 1996
	Coffs Harbour	STP grounds	42	Current	NSW DLWC 1996
	Coffs Harbour	Sand washing	16	Current	NSW DLWC 1996
	Coffs Harbour	Dust suppression		Current	NSW DLWC 1996
	Coffs Harbour	University	2	Current	NSW DLWC 1996
	Coffs Harbour	Bowling club	1	Current	NSW DLWC 1996
	Corowa	Pasture & trees	500	Current	NSW DLWC 1996
	Cootamundra	Animal fodder	-	Current	NSW DLWC 1996
	Cowra	Irrigation	-	Current	NSW DLWC 1996
	Deniliquin	Rye grass and clover	50 hectares	Current	McLeod & Hawes 1992: 1
	Dora Creek	Industrial - Eraring power station	1 460 (4 ML/d)	Under construction	NSW RWCC 1995: 2
	Dubbo	Bunglegumbie treelot	80	Current	McLeod & Hawes 1992
	Dubbo	Pasture	900	Current	NSW DLWC 1996
	Dubbo	Animal fodder	360	Current	NSW DLWC 1996
	Eurobodalla	2 golf courses	4	Current	NSW DLWC 1996
	Forbes	Irrigation	100	Current	NSW DLWC 1996
	Glenn Innes	Golf course	20	Current	NSW DLWC 1996
	Gosford	STP grounds	200	Current	NSW DLWC 1996
	Goulbourn	Oats and lucerne (summer only)	633 (5.2 ML/d)	Current	McLeod & Hawes 1992: 1
	Grafton	Tea-tree plantation	100	Current	NSW DLWC 1996
	Griffith	CSIRO filter project	-	Current	NSW DLWC 1996
	Gulgong	Dust suppression and coal washing	-	Current	Warner et al. 1992: 2
	Gundagai	Golf course	250	Proposed	NSW DLWC 1996
	Gunning	Pasture	-	Current	NSW DLWC 1996
	Harden	Public gardens	10	Current	NSW DLWC 1996

State	Location	Type of Scheme	Volume ML/a	Status	Reference
	Harden	Public lawns	20	Current	NSW DLWC 1996
	Harden	Golf courses	60	Current	NSW DLWC 1996
	Harden	Playing fields	40	Current	NSW DLWC 1996
	Hastings	STP grounds	8	Current	NSW DLWC 1996
	Hastings	Golf courses	40	Current	NSW DLWC 1996
	Hastings	Playing fields	11	Current	NSW DLWC 1996
	Hastings	Dune stabilisation	8	Current	NSW DLWC 1996
	Hastings	Road watering	10	Current	NSW DLWC 1996
	Hawkesbury	STP grounds	5	Current	NSW DLWC 1996
	Hawkesbury	Pasture	250	Current	NSW DLWC 1996
	Hawkesbury	Animal Fodder	200	Current	NSW DLWC 1996
	Hawkesbury	Woodlots	100	Current	NSW DLWC 1996
	Illawarra	Industrial Cooling	2 190 (<6 ML/d)	Current	Warner et al. 1992: 1
	Illawarra	Steel works	-	Current	Warner et al. 1992: 2
	Illawarra	Various	-	Planned	Warner et al. 1992: 2
	Jerilderie	Racing track	25	Current	NSW DLWC 1996
	Kempsey	Golf courses	170	Current	NSW DLWC 1996
	Kempsey	Race course	50	Current	NSW DLWC 1996
	Kempsey	Pasture irrigation	435	Current	NSW DLWC 1996
	Kempsey	Tea-tree plantation	10	Current	NSW DLWC 1996; NSW RWCC 1995: 2
	Lismore	Turf farm irrigation	-	Current	NSW DLWC 1996; NSW RWCC 1995: 2
	MacLean	Golf courses	98	Current	NSW DLWC 1996
	Mulwaree	Pasture Irrigation	27	Current	NSW DLWC 1996
	Murray	Farm	2	Current	NSW DLWC 1996
	Muswellbrook	Golf courses	152	Current	NSW DLWC 1996
	Muswellbrook	Playing fields	43	Current	NSW DLWC 1996
	Muswellbrook	Pasture	60	Current	NSW DLWC 1996
	Nambucca	Agriculture	-	Current	NSW DLWC 1996
	Narrabri	STP grounds	-	Current	NSW DLWC 1996
	Newcastle	Dust suppression and coal washing	2 555 (7 ML/d)	Current	Warner et al. 1992: 2
	Nymbioda	Golf courses	1	Current	NSW DLWC 1996
	Orange	Gold mine	-	Proposed	NSW DLWC 1996
	Parkes	Mine	1 000	Current	NSW DLWC 1996
	Parkes	Jockey club	5	Current	NSW DLWC 1996
	Parkes	Farm	100	Current	NSW DLWC 1996
	Quakers Hill	Potable	1 460 (4 ML/d)	Planned	AWWA* 1996e: 1
	Queenbeyan	Stock yards and pasture (summer only)	754 (6.2 ML/d)	Current	McLeod & Hawes 1992: 1
	Queenbeyan	STP grounds	13	Current	NSW DLWC 1996
	Rouse Hill	Non-potable domestic and landscape irrigation	10 950 (30 ML/d)	Planned	Fisher et al 1992
	Scheyville	Non-potable domestic and landscape irrigation	1 387 (3.8 ML/d)	Planned	Hamlyn-Harris 1992: 1
	Singleton	Pasture irrigation	250	Current	NSW DLWC 1996
	Shoalhaven	Agriculture	1 460	Current	NSW DLWC 1996
	Shortland (Hunter Valley)	Industrial	1 825 (3–5 ML/d)	Planned	NSW RWCC 1996: 5
	Taree	-	1	Current	NSW DLWC 1996
	Toukley	Wetland replenishment	3 358 (9.2 ML/d)	Current	GHD 1983: 18
	Temora	STP grounds	5	Current	NSW DLWC 1996
	Temora	Public gardens	20	Current	NSW DLWC 1996
	Temora	Public lawns	70	Current	NSW DLWC 1996
	Temora	Golf courses	100	Current	NSW DLWC 1996

State	Location	Type of Scheme	Volume ML/a	Status	Reference
	Temora	Playing fields	100	Current	NSW DLWC 1996
	Temora	Dog track	50	Current	NSW DLWC 1996
	Temora	Cemetery grounds	55	Current	NSW DLWC 1996
	Tumbarumba	Apple orchards	-	Current	NSW DLWC 1996
	Tumut	Golf course	20	Current	NSW DLWC 1996
	Tweed Heads	Golf course	700	Current	NSW DLWC 1996
	Wagga Wagga	Golf courses	20	Current	NSW DLWC 1996; Earnshaw 1992
	Wagga Wagga	Public gardens	100	Current	NSW DLWC 1996
	Wagga Wagga	Public lawns	100	Current	NSW DLWC 1996
	Wagga Wagga	Golf courses	4	Current	NSW DLWC 1996
	Wagga Wagga	Playing fields	150	Current	NSW DLWC 1996
	Wagga Wagga	Race courses	30	Current	NSW DLWC 1996
	Wagga Wagga	Cemetery	100	Current	NSW DLWC 1996
	Wagga Wagga	Pasture irrigation	15	Current	NSW DLWC 1996
	Wagga Wagga	Truck wash	25	Current	NSW DLWC 1996
	Wagga Wagga "Flushing Meadows"	Silviculture	4.5 ha	Started 1991	Myers et al 1992
	Wakool	Pasture	-	Current	NSW DLWC 1996
	Warren	Playing fields	2 ha	Current	NSW DLWC 1996
	Wentworth	Golf courses	10	Current	NSW DLWC 1996
	West Wyalong	Golf Course	134 (1.1 ML/d)	Current	GHD 1983
	Wollondilly	Woodlot	58	Current	NSW DLWC 1996
	Woolgoolga	Cropping trial	1 338 (0.2-11 ML/d)	Trial	McLennan & Murtagh 1992: 1
	Wyong	STP grounds	210	Current	NSW DLWC 1996
	Young	Golf course	-	Current	NSW DLWC 1996
Total reuse volume of above NSW schemes			**38 330**		
Total reuse estimate for NSW			**35 000**		Schlafrig and Anderson 1992: 4
Total estimated sewage output for NSW			**710 000**		

State	Location	Type of Scheme	Volume ML/a	Status	Reference
VIC	Alexandria	Irrigation	124	Current	Semple 1995
	Ararat	Irrigation	200	Current	Semple 1995
	Ballan	Irrigation	90	Current	Semple 1995
	Beechworth	Irrigation	140	Current	Semple 1995
	Benalla	Irrigation	270	Current	Semple 1995
	Bendigo	Irrigation	585	Current	Semple 1995
	Birchip	Irrigation	78	Current	Semple 1995
	Bonnie Doon	Irrigation	35	Current	Semple 1995
	Bright	Irrigation	73	Current	Semple 1995
	Broadford	Irrigation	100	Current	Semple 1995
	Charlton	Irrigation	10	Current	Semple 1995
	Chiltern	Irrigation	52	Current	Semple 1995
	Cobram	Irrigation	925	Current	Semple 1995
	Coronet Bay	Irrigation	25	Current	Semple 1995
	Corryong	Irrigation	50	Current	Semple 1995
	Cowes	Irrigation	90	Current	Semple 1995
	Daldy Road	Irrigation	900	Current	Semple 1995
	Daylesford	Irrigation	200	Current	Semple 1995
	Dimboola	Irrigation	122	Current	Semple 1995
	Dinner Plain	Irrigation	17	Current	Semple 1995
	Donald	Irrigation	550	Current	Semple 1995
	Drouin	Irrigation	203	Current	Semple 1995
	Echuca	Irrigation	750	Current	Semple 1995
	Edenhope	Irrigation	1	Current	Semple 1995
	Eildon	Irrigation	39	Current	Semple 1995
	Embankment Drive	Irrigation	71	Current	Semple 1995
	Euroa	Irrigation	150	Current	Semple 1995
	Halls Gap	Irrigation	72	Current	Semple 1995
	Hamilton	Irrigation	500	Current	Semple 1995
	Heathcote	Irrigation	130	Current	Semple 1995
	Heyfield	Irrigation	130	Current	Semple 1995
	Heywood	Irrigation	71	Current	Semple 1995
	Horsham	Irrigation	200	Current	Semple 1995
	Inverloch	Irrigation	20	Current	Semple 1995
	Jeparit	Irrigation	75	Current	Semple 1995
	Kaniva	Irrigation	91	Current	Semple 1995
	Kerang	Irrigation	750	Current	Semple 1995
	Koorlong	Silviculture	1 095 (9 ML/d)	Current	Martin 1996: 27
	Kyabram	Irrigation	945	Current	Semple 1995
	Kyneton	Irrigation	134	Current	Semple 1995
	Lakes Entrance	Irrigation	500	Current	Semple 1995
	Maffra	Irrigation	395	Current	Semple 1995
	Mansfield	Irrigation	330	Current	Semple 1995
	Maryborough	Irrigation	180	Current	Semple 1995
	McRoberts Road	Irrigation	150	Current	Semple 1995
	Melton	Lucerne and pasture	3 010	Upgrade	Nolan 1993: 2
	Merebein	Irrigation	145	Current	Semple 1995
	Metung	Irrigation	35	Current	Semple 1995
	Mildura	Irrigation	2 415	Current	Semple 1995
	Mooroopna	Irrigation	400	Current	Semple 1995
	Murchison	Irrigation	44	Current	Semple 1995
	Murtoa	Irrigation	90	Current	Semple 1995
	Nagambie	Irrigation	130	Current	Semple 1995
	Nathalia	Irrigation	145	Current	Semple 1995
	Newmerella	Irrigation	240	Current	Semple 1995
	Nhill	Irrigation	183	Current	Semple 1995
	Numurkah	Irrigation	474	Current	Semple 1995
	Parwan South	Irrigation	720	Current	Semple 1995
	Paynesville	Irrigation	1	Current	Semple 1995
	Port Arlington	Irrigation	330	Current	Semple 1995
	Rainbow	Irrigation	90	Current	Semple 1995

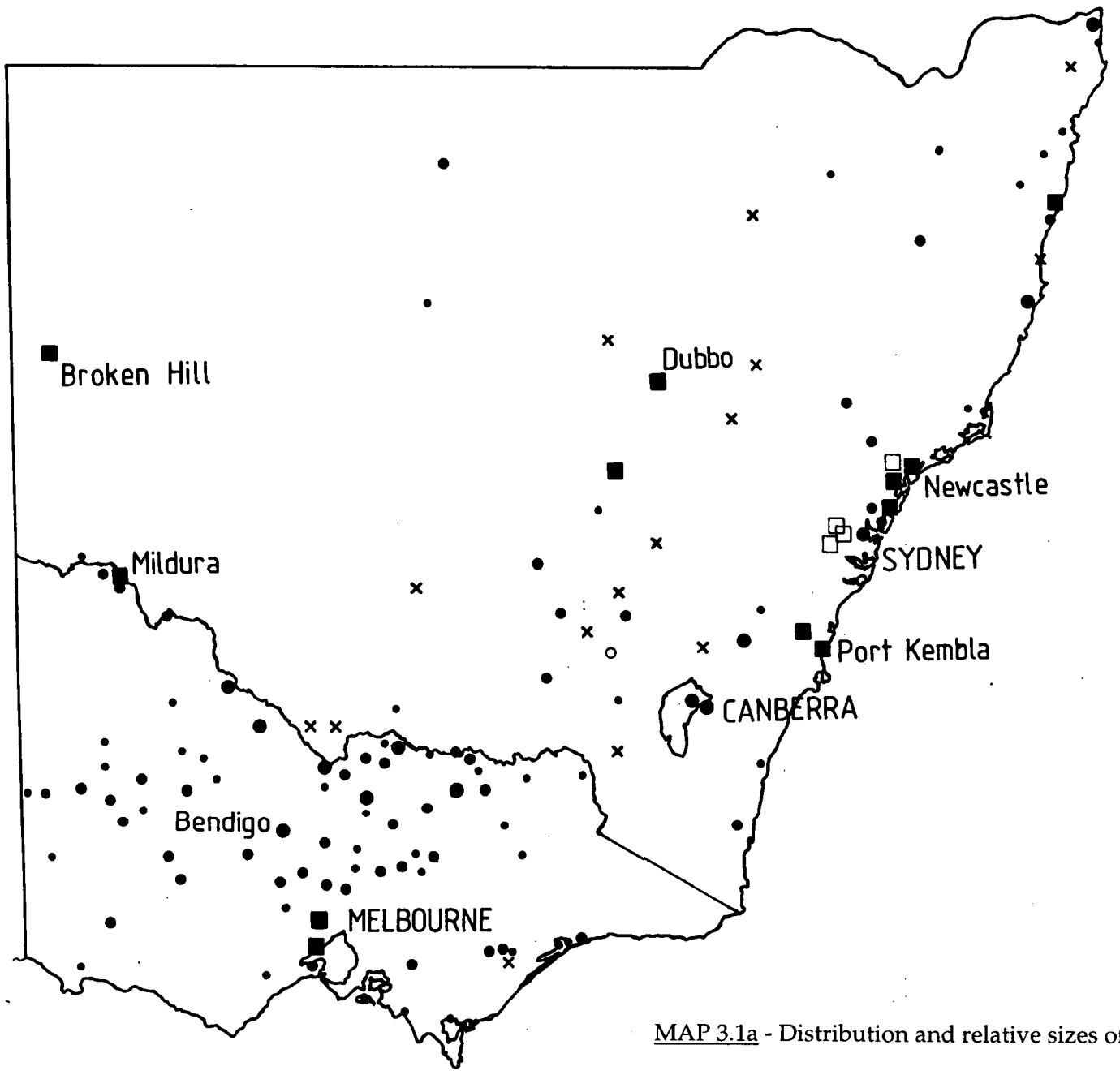
State	Location	Type of Scheme	Volume ML/a	Status	Reference
	Redcliffs	Sport facilities	166	Current	Semple 1995
	Robinvale	Irrigation	230	Current	Semple 1995
	Rochester	Irrigation	72	Current	Semple 1995
	Romsey	Irrigation	215	Current	Semple 1995
	Rutherglen	Irrigation	190	Current	Semple 1995
	Sea Lake	Irrigation	70	Current	Semple 1995
	Serviceton	Irrigation	17	Current	Semple 1995
	Seymour	Irrigation	100	Current	Semple 1995
	Simpson	Irrigation	9	Current	Semple 1995
	Stawell	Irrigation	180	Current	Semple 1995
	Stratford	Irrigation	90	Current	Semple 1995
	Strathmerton	Irrigation	50	Current	Semple 1995
	Swan Hill	Irrigation	900	Current	Semple 1995
	Tallangatta	Irrigation	80	Current	Semple 1995
	Tarraville	Irrigation	230	Current	Semple 1995
	Tatura	Irrigation	840	Current	Semple 1995
	Tongala	Irrigation	145	Current	Semple 1995
	Toora	Irrigation	2	Current	Semple 1995
	Wallan	Irrigation	140	Current	Semple 1995
	Wangaratta	Irrigation	750	Current	Semple 1995
	Warracknabeal	Irrigation	225	Current	Semple 1995
	Werribee	Irrigation	13 000	Current	Semple 1995
	West Wodonga	Irrigation	300	Current	Semple 1995
	Winchelsea	Irrigation	91	Current	Semple 1995
	Wycheproof	Irrigation	70	Current	Semple 1995
	Yarrawonga	Irrigation	100	Current	Semple 1995
	Yea	Irrigation	130	Current	Semple 1995
Total reuse volume of above VIC schemes			**38 462**		
Total reuse estimate for VIC			**36 757**		Les Semple 1995, pers. comm., 1/8; Bowmer & Laut 1992: 201
Total estimated sewage output for VIC			**510 000 (320 000)**	1992 figure (Melbourne)	Les Semple 1996, pers. comm., 22/8; Environment Victoria 1994: 32

State	Location	Type of Scheme	Volume ML/a	Status	Reference
QLD	Albert Shire	Golf courses	-	Current	QLD DPIF 1992: 27
	Pine Rivers Shire	Golf courses	-	Current	QLD DPIF 1992: 27
	Redland Shire	Golf courses	-	Current	QLD DPIF 1992: 27
	Moreton Shire	Golf courses	-	Current	QLD DPIF 1992: 27
	Maroochy Shire	Golf courses	-	Current	QLD DPIF 1992: 27
	Hervey Bay City	Sugar cane & silviculture			
	Brisbane City	Five golf courses	-	Current	QLD DPIF 1992: 27
	Gold Coast	Greenspaces	243 (2 ML/d)	Current	GHD 1983: 24
	Kingaroy	Farmland	-	Current	GHD 1983: 24
	Mount Isa	Horse grazing	30 ha	Current	GHD 1983: 24
	Mount Isa	Greenspaces	-	Current	QLD DPIF 1992: 28
	University of QLD	Greenspaces	-	Current	GHD 1983: 24
	Warwick	horse stud	-	Current	GHD 1983: 24
	28 inland towns	Pasture and fodder	-	Current	GHD 1983: 24
Total reuse estimate for QLD			**32 000**	1992 figure	Andrew Bryan 1996, pers. comm., 19/8
Total estimated sewage output for QLD			**305 000**	1992 figure	Andrew Bryan 1996, pers. comm., 19/8
SA	Angaston		-	Planned	Richard Desmier 1996, pers. comm., 25/3
	Bird in Hand		-	Planned	Desmier 1996
	Bolivar	Lucerne, tomatoes and potatoes	2 700	Current	Richard Desmier 1995, pers. comm., 3/7
	Christies Beach	Recreation	21	Current	Desmier 1995
	Glenelg	Recreation areas (mainly golf courses) and Adelaide Airport	1 100 (<40 ML/d)	Current	Desmier 1995
	Gumeracha		-	Planned	Desmier 1996
	Loxton	Silviculture trial (1/3 primary effluent)	700	Started 1984	Allender 1988: 26
	Mannum	Golf course	130	Current	Desmier 1995
	Murray Bridge	Irrigation	176 (<1.45 ML/d)	Current	Desmier 1996
	Myponga		-	Planned	Desmier 1996
	Pt. Augusta West	Golf course	150	Current	Desmier 1995
	Victor Harbor	Golf course	80	Current	Desmier 1996
Total reuse volume of above SA schemes			**5 057**		
Total reuse estimate for SA			**8 800**		Desmier 1996
Total estimated sewage output for SA			**102 200**		Desmier 1996

State	Location	Type of Scheme	Volume ML/a	Status	Reference
WA	35 country towns (Beenyup, Kalgoolie, Kambalda, Newman,...)	Landscape, agriculture, mining and sports grounds	1 460-	Current	Julie Phelps 1995, pers. comm., 3/7; Ivan Unkovich WAWA, 1996, pers. comm., 26 Aug.
	Kwinana	Industrial	10 950 (30 ML/d)	Proposed	John Schlafrig, 1996, pers. comm., 19/7
	Mosman Park	Landscape	-	Current	John Schlafrig, 1996, pers. comm., 19/7
	Albany	Irrigation of trees	1 200	Current	Ivan Unkovich WAWA, 1996, pers. comm., 26 Aug.
	Karratha	Greenspaces	365	Current	Ivan Unkovich WAWA, 1996, pers. comm., 26 Aug.
	Aerobic sewage tanks (Perth)	Domestic	1000 units	Current	Julie Phelps 1995, pers. comm., 3/7
Total reuse estimate for WA			**>2 660**		Ivan Unkovich WAWA, 1996, pers. comm., 26 Aug.
Total estimated sewage output for WA			**96 000**		WAWA 1994/5
NT	Alice Springs	Silviculture and lucerne	-	Current	Jackson & Steitieh 1990: 24
	North Lakes (Darwin)	Greenspace (dry period only)	219 (1.8 ML/d)	Started 1983	Jackson & Steitieh 1990: 24
	Yulara (Ayers Rock)	Sports oval	-	Current	Jackson & Steitieh 1990: 24
Total reuse estimate for NT			**2 000**	1983 figure	GHD 1991
Total estimated sewage output for NT			**6 000**	1983 figure	GHD 1991
TAS	Swansea	Agriculture	<44	Current	LPH Pty Ltd nd
	West Tamar	Golf course	<89	Current	Wright 1994
Total reuse estimate for TAS			**<133**		GHD 1991
Total estimated sewage output for TAS			**30 000**	1983 figure	GHD 1991
ACT	Demonstration	Greenspaces	548 (4.5 ML/d)	Current	GHD 1983: 30
Total Volume of the Above Reuse Schemes (direct use only)			**122 390**		
Total Reuse Estimate Volume for Australia (includes indirect reuse)			**200 646 (11% of total)**		Anderson 1996: 5; Schlafrig and Anderson 1992: 4
Total Estimated Sewage Output for Australia			**1 767 200**		

* Australian Water and Wastewater Association
# Gutteridge, Haskins and Davey Pty Ltd
@ NSW Department of Land and Water Conservation
- No data available

Maps 3.1a, b & c illustrate the geographical distribution and the relative sizes of wastewater reuse schemes throughout the country based on the details in Table 3.1. Of note, there is a considerable concentration of reuse schemes in the Eastern states. Victoria has a fairly even distribution of schemes throughout the state, whereas the other states tend to have schemes focussed around the major urban centres where domestic effluent is readily available.

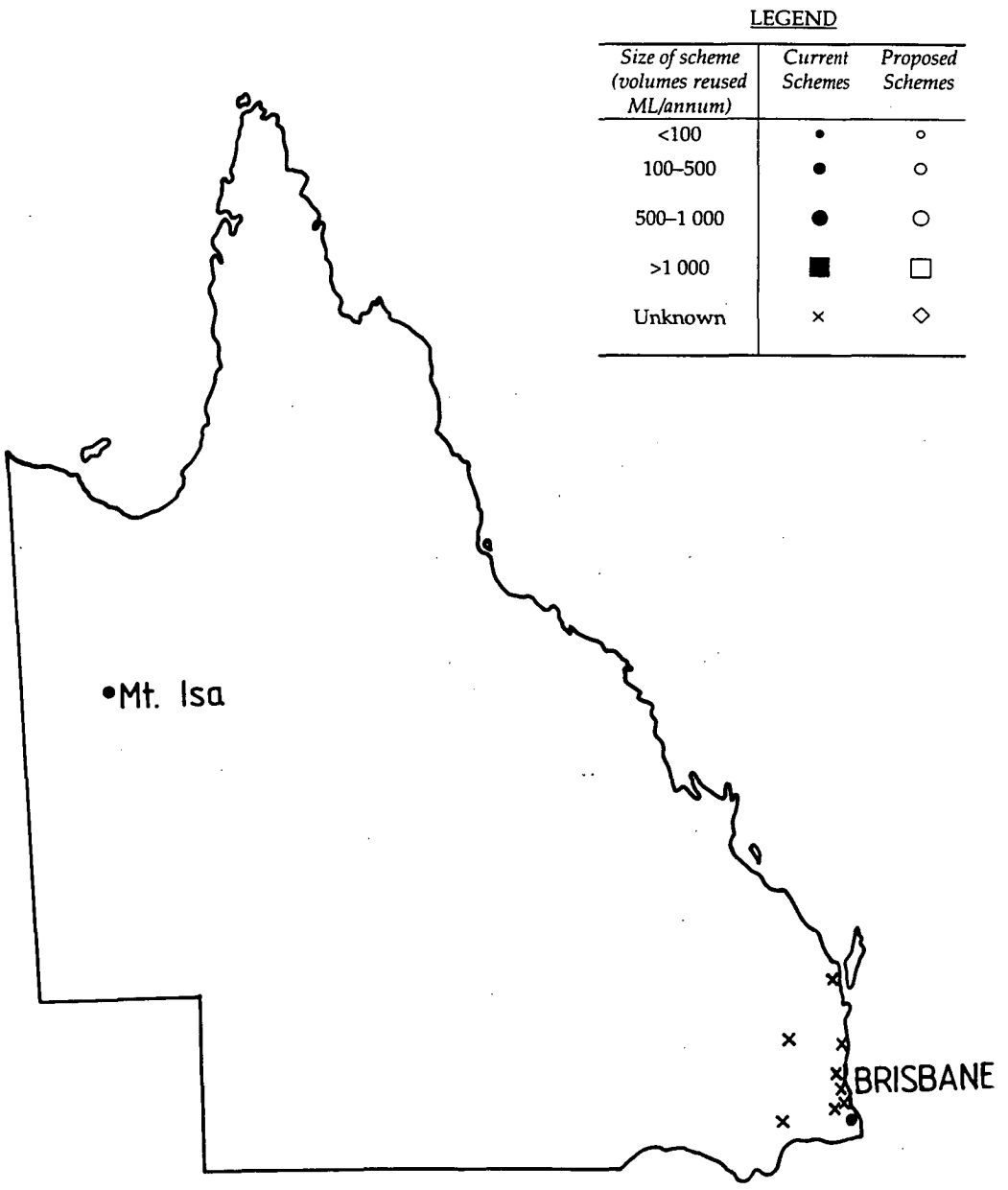


LEGEND

Size of scheme (volumes reused ML/annum)	*Current Schemes*	*Proposed Schemes*
<100	•	○
100–500	●	○
500–1 000	●	○
>1 000	■	□
Unknown	×	◇

MAP 3.1a - Distribution and relative sizes of reuse schemes in NSW, ACT and Victoria

MAP 3.1b - Distribution and relative sizes of reuse schemes in QLD



MAP 3.1c - Distribution and relative sizes of reuse schemes in SA, WA and NT

LEGEND

Size of scheme (volumes reused ML/annum)	*Current Schemes*	*Proposed Schemes*
<100	•	○
100–500	●	○
500–1 000	●	○
>1 000	■	□
Unknown	×	◇

Table 3.2 provides summary totals of the data in Table 3.1 for national and statewide wastewater reuse and sewage flow totals for 1983 and 1996.

1983	*REUSE VOLUME GL*	*TOTAL SEWAGE FLOW GL*	*PERCENTAGE REUSE*
NSW	14.0	550.0	2.5
VIC	13.5	350.0	3.9
QLD	5.0	200.0	2.5
SA	6.8	100.0	6.8
WA	8.0	60.0	13.3
NT	2.0	6.0	33.3
TAS	0.0	30.0	0.0
TOTALS	49.3	1296.0	3.8
1996	*REUSE VOLUME*	*TOTAL SEWAGE FLOW*	*PERCENTAGE REUSE*
NSW	38.33	710.0	5.4
VIC	38.46	518.0	7.4
QLD	32.00	305.0	10.5
SA	8.80	102.2	8.6
WA	2.66	96.0	2.8
NT	2.0*	6.0*	33.3
TAS	0.13	30.0	0.4
TOTALS	122.39	1767.2	6.9

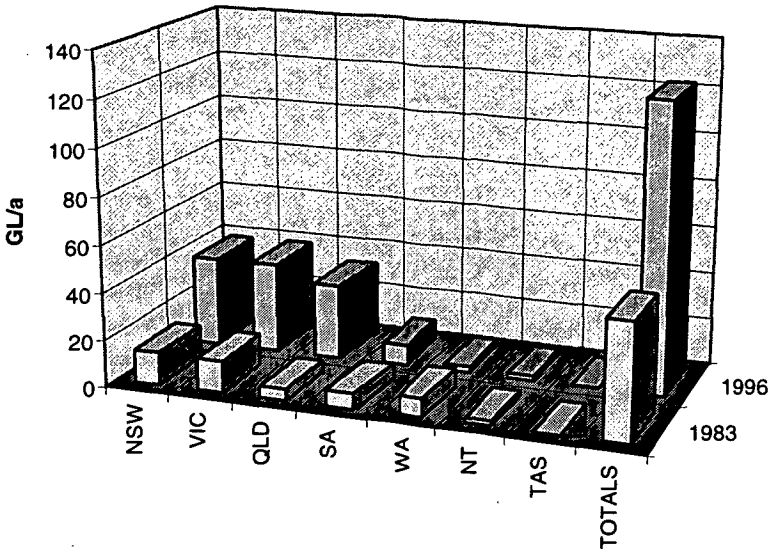
* 1983 figures

TABLE 3.2 - Summary table of national and state total reuse and sewage flows

Comparing the national percentage direct reuse between 1983 and 1996, there has been at least a doubling of reuse even though total reuse that includes indirect reuse has remained fairly static. This would seem to reflect a move towards are more intentional reuse of wastewater effluent. Although current figures for NT have not been obtained they would appear to still be the highest proportional users of effluent. Of note, Queensland followed by SA are the next highest proportional users of effluent. Figure 3.1 provides a clearer indication of where the growth in reuse schemes has occurred in each state over the last 13 years.

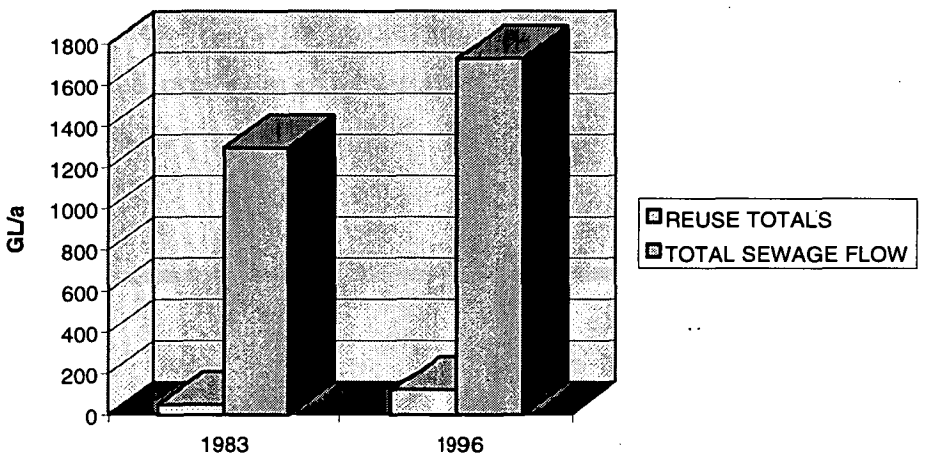
From this figure it is clear that NSW and Victoria are the largest users of recycled effluent whereas Queensland has experienced the fastest growth in reuse over the last 13 years. Figure 3.2 provides an indication of the growth of reuse schemes in Australia over the last 13 years in comparison with the increase of total sewage volumes over this time. Even though reuse has more than doubled over the last 13 years it still represents quite a small proportion of the total wastewater flow.

FIGURE 3.1 - Comparison of Wastewater Reuse Totals Between 1983-1996



Figures for 1983 are based on GHD (1983) report

FIGURE 3.2 - Comparison of Reuse Volumes to Total Sewage Flow in Australia 1983-1996



3.5.1 Reuse in New South Wales

Most sewage in NSW received only primary treatment before being discharged to the ocean in the early 1980s (GHD 1983: 16) and this continues to be the case. The remainder of the sewage volume was treated by 215 secondary treatment plants with more than 60 supplying effluent to some form of land irrigation. The effluent was supplied without charge.

In 1981, a 'Task Force on Use of Reclaimed Water' found that in many dry inland towns, reuse enabled provision of greenspace amenities that would otherwise not be

possible and in some instances it was found that the cost of expensive potable augmentation works could be deferred by reclaiming water (GHD 1983: 19).

Today, approximately 50 of 180 local Councils are reusing effluent with an average of 400–500 ML/a being reused per scheme. Wastewater reuse outside the Sydney metropolitan area is about 10% of 150 000 ML/a of the total wastestream. Perc Wyles (1995, pers. comm., 11 July), Manager of Water Reclamation and Reuse, Sydney Water, believes only approximately 1% of the 470 000 ML/a of wastewater generated in the Sydney area is presently being reused. John Anderson (1996, pers. comm., 19 July & 22 Aug.) estimates that reuse throughout the state is at about 5% of the 660 000 ML/a total sewage flow[3] which is close to the estimate of 5.4% in Table 3.1.

Large industrial water consumers, such as, coal mines and power stations in the Hunter Valley district reuse approximately 10% of the 40 000 ML/a of wastewater generated in the region. An industrial reuse scheme is under construction that will utilise purified TSE for boiler feed water in the Eraring Power Station, Dora Creek, NSW (NSW RWCC 1995: 2). Port Kembla uses 365–730 ML/a for industrial reuse which is planned to increase to 3 650 ML/a by the year 2000.

In terms of predicting the growth of reuse in the future there is a difference of opinion in the water supply industry. Anderson optimistically predicted that reuse is projected to double by the year 2000 (Anderson 1996: 4) whereas Mr. Wyles, more conservatively, projects that only a total of 4% of the NSW wastewater stream can be reused by the year 2000 due to the prohibitive cost of duplicating reticulation systems in urban areas. Of the potential users, golf course needs are seasonal which provides a problem of storage in winter, urban industry use is low and unlikely to increase because most large industries are regarded by water authorities as unreliable potential users in that they could relocate or move offshore. The main potential area for development is residential reuse where dual reticulation systems are installed in new development areas.

Key developments over the last few years have been in the area of non-potable residential reuse. In 1989 to 1991 a demonstration residential non-potable reuse scheme was designed by the NSW Public Works Department and built by the

[3] This figure is based on the dry weather flow plus 10–15%.

Shoalhaven City Council to help obtain an objective assessment of operating requirements, risk and community acceptance (Wilkins and Anderson 1991: 30; Wilkins 1992: 1). It is believed to be the first of its kind in Australia. The scheme was accepted by the community and no health changes were observed. This paved the way for the NSW Recycled Water Co-ordination Committee to develop guidelines for urban reclaimed water use. These guidelines have been utilised to plan the Rouse Hill and Scheyville dual reticulation water supply scheme.

Rouse Hill, and nearby Scheyville, form a new suburban growth area that is incorporating a dual domestic reticulation system and provision of reclaimed water for industrial and irrigation purposes (Fischer et al. 1992; Hamlyn-Harris 1992). The Rouse Hill project is largely complete although it will be some time before there is sufficient load to fully commission the plant (NSW RWCC 1994: 3). Population pressures on the already environmentally stressed Hawkesbury-Nepean River catchment has encouraged the Sydney Water Board to implement water conservation strategies such as this one. The fundamental objective of this scheme is to return wastewater to the water cycle in ways which protect public health and the environment. Sydney Water is also planning to apply similar management strategies in the new outer urban development areas of South Creek Valley and Macarthur South, near Sydney. Wagga Wagga City Council have been proceeding with construction of a similar scheme, to be commissioned in 1995, involving 75 residential blocks and 10 five acre properties (NSW RWCC 1994: 3).

How much reuse will continue to expand, therefore, remains to be seen, although with the momentum of current expansion, more of the public will have exposure to such schemes thereby warranting continued study of the health risks involved.

3.5.2 Reuse in Victoria

In 1976, Victoria formed the 'Reclaimed Water Committee' in order to establish some firm reuse guidelines. They also initiated a series of studies on wastewater reuse, including as assay on viruses in effluent and field trials of growing vegetables (GHD 1983: 20; Smith 1982).

Les Semple (VIC Dept. of Natural Resources and Environment, 1995, pers. comm., 1 Aug.) listed 85 Victorian STPs that were supplying effluent for reuse in 1993/94 out of a total of 174 plants. The effluent discharged to land totalled 36 757 ML/a and he

anticipates this will increase to 42 211 ML/a by the year 1999. The total wastewater treated for the state in 1993 amounted to 518 000 ML/a (Les Semple 1996, pers. comm., 22 Aug.). Therefore, as a percentage, 7.1% of Victorian wastewater is reused.

In 1993, Melbourne produced 320 000 ML of sewage and it was estimated that less than 1 000 ML/a was used for recycling (Conservation Council of Victoria 1993a: 6),[4] most of it used for golf courses and horticultural land.

Of all the effluent reuse programs in Australia, the 4 300 ha Werribee Sewage Treatment farm, which commenced in 1897, is the largest and one of the oldest. It used raw sewage in the irrigation of pasture grazed by beef cattle and sheep during seven months of the year. It now treats 55% of Melbourne's sewage but reuses only a portion of this and the rest is discharged into Port Philip Bay. The South Eastern Purification Plant at Carrum handles 40% of Melbourne's waste and very little is reused. Melbourne Water is presently trying to encourage reuse for large water users (Conservation Council of Victoria 1993a: 3; Environment Victoria, Inc: 1994: 33). Many country towns practice flood irrigation of effluent on pasture used for sheep or cattle grazing.

3.5.3 Reuse in Queensland

In April 1993, a comprehensive survey was conducted by the QLD Department of Natural Resources of effluent reuse schemes in the state. This information was summarised into a report titled, 'Sewage Effluent Generation, Disposal and Reuse in Queensland - A Survey of Current Practices'. The raw data from which the report was compiled, providing information on total effluent being recycled from each STP, are not available to the public and could not be used in this thesis. However, the Department could provide overall figures for the state. The total sewage flow to treatment plants in 1992 was 305 000 ML/a and the total amount discharged to land was 32 000ML/a (Andrew Bryan, QLD Dept. of Natural Resources 1996, pers. comm., 25 July & 19 Aug.). How much of the effluent discharged to land that is beneficially reused is not certain. According to the above figures, the percentage of wastewater reused may be as high as 10%.

[4] The source does not indicate if this figure includes or excludes the Werribee Treatment Farm.

Of the 191 sewage treatment plants in QLD, 144 use some form of land application. Golf courses are the largest consumer of the effluent, collectively using effluent from 51 STPs (Andrew Bryan 1996, pers. comm., 22 Aug.). Twenty-eight inland towns used effluent in a minor way for pasture and fodder irrigation. Golf courses and sports grounds are the most prevalent forms of landscape reuse in the state, totalling twenty six in 1983 and no doubt this has increased since then (GHD 1983: 24). Several powerstations had considered the possibility of using effluent but technical problems had stopped further development (GHD 1983: 25).

3.5.4 Reuse in South Australia

Wastewater reuse is not new to the state. Adelaide's first sewage treatment scheme at Islington, built in 1881, utilised effluent, as did the Glenelg STP by the turn of the century (Martin 1996: 27). Landscape irrigation has been the major use of effluent in South Australia. Glenelg STP has used effluent for landscape irrigation since 1933 and part of Christies Beach STP effluent was committed for landscape irrigation in the 1980s. Port Augusta West STP effluent is used on a golf course and another golf course in Barama used mixed effluent. Charges have accompanied the use of South Australian effluent (GHD 1983: 29).

At the last 'Re-use of Sewage Effluent' seminar held in Adelaide in 1995, the Minister responsible for water resources stated that 'the reuse of resources is a logical path' and announced that the SA government would soon release a new state water plan which for the first time would consider wastewater as a resource (Martin 1996: 26). Major initiatives for wastewater reuse are being proposed for the Glenelg and Bolivar plants which are the largest in the State (Martin 1996; Richard Desmier, SA Department of Engineering and Water Supply 1996, pers. comm., 25 Mar.). A proposed pipeline from Bolivar Sewage Treatment Works to Virginia, on the northern Adelaide Plains, is hoped to utilise 80-100% of the total effluent discharge. In 1983, 7 350 ML/a of effluent had been allocated for vineyards, lucerne, pasture, cereal and vegetables, and another 550 ML/a for landscape irrigation at Salisbury compared to a total output of 43 000 ML/a from the STP (GHD 1983: 27). Current usage has been around 2 700 ML/a that represents 7% reuse of the STP effluent (R. Desmier 1995, pers. comm., 3 July).

Murray Bridge and Mannum STP have total reuse schemes and plans for reuse in Angaston, Bird-in-Hand, Gumeracha and Myponga are being drafted (R. Desmier 1996, pers. comm., 25 Mar.). In addition 20 of the 100 septic tank effluent drainage

schemes involve partial reuse (Martin 1996: 27). New urban developments in South Adelaide are being planned to include wastewater recycling on agricultural spaces, decentralised sewage treatment, dual reticulation systems, wetlands for stormwater management and groundwater recharge (NSW RWCC 1995: 4).

From Table 3.1, total reuse for the state amounts to approximately 8 800 ML/a or 8.6% of the total 102 200 ML/a sewage flow treated for the state.

3.5.5 Reuse in Western Australia

By the early 1980s in rural WA, quite a number of reuse schemes were operating. The majority of schemes were landscape irrigation because the Public Works Department had encouraged reuse via financial subsidies. This resulted in 35 country towns using reclaimed water for sports grounds. Raw sewage was firstly primary treated, then stored in a lagoon where it was chlorinated before use. These schemes continue to be highly successful. Only one agricultural scheme was operating which involved the irrigation of an orchard with effluent at Kalgoorlie. In addition, a CSIRO silviculture trial was also being conducted at Beenyup. The Perth metropolitan area had no urban reuse schemes operating in 1983 (GHD 1983: 25) although there was unintentional aquifer recharge though septic tank seepage from 110 000 homes. Perth had been experimenting with spreading basins for aquifer recharge in the Canning Vale area. Results to date indicated that the soil could not adequately remove phosphorus from the effluent. Kalgoolie also used wastewater for charging an artificial lake, Kambalda used effluent as mine process water and Newman used it for dust control.

The potential demand for reclaimed water for industrial uses is expected to be quite high in the very dry and isolated industrial and mining centres, yet not enough domestic wastewater can be generated due to their small and widely spread populations. Partially treated wastewater has been used for irrigation of grass and crops using effluent from food processing, meat and domestic wastewater plants (Gale 1988: 22, 23).

To date, two types of reuse are currently being employed in WA (Julie Phelps WA Department of Health 1995, pers. comm., 13 July). The first is by local authorities supplying effluent for landscape irrigation mostly in the summer time. Forty schemes are operating in about 30 of about 140 municipalities. Total estimate of WA daily volume of sewage treated is 263 ML (WAWA 1994/95) or 96 000 ML/a. Thirty five

country towns use approximately 8 ML/d (Ivan Unkovich WAWA, 1996, pers. comm., 26 Aug.) over a six month period or 1 460 ML/a (the volume reused in Karratha would be included in this total). Therefore total reuse for the state is greater than 2 660 ML/a or >2.8% of the wastewater volume treated. This will increase to >14% when the industrial reuse scheme in Kwinana is fully operational. Recently, the Premier has commissioned an effluent irrigated treelot to divert sewage from polluting the marine environment in Albany (Hodgkins 1996: 309). The second type of reuse is domestic, whereby aerobic sewage tank units, approximately 1 000 in number, supply effluent for garden watering.

With regard to the future, the Water Authority of Western Australia has recently published its Wastewater 2040 Strategy which ranked recycling options for adoption. Urban reuse rather than agricultural and silvicultural reuse were predicted to be more economically viable (NSW RWCC 1995: 4).

3.5.6 Northern Territory

Irrigation of effluent was restricted to a silviculture irrigation schemes in Alice Springs and an experimental silviculture scheme in Darwin which started in 1972 and was abandoned in 1978 due to the severe damage of cyclone Tracy. Landscape irrigation of effluent was being planned in the early 1980s (GHD 1983: 29) and in 1990 the Territory had established a few small reuse schemes currently operating in Darwin, Alice Springs, Yulara and in a few aboriginal communities (Jackson & Steitech 1990: 24).

3.5.7 Reuse in the Australian Capital Territory

A demonstration scheme using 4.5 ML/d for greenspaces was operating in the A.C.T. during the 1980s (GHD 1983: 30).

3.5.8 Reuse in Tasmania

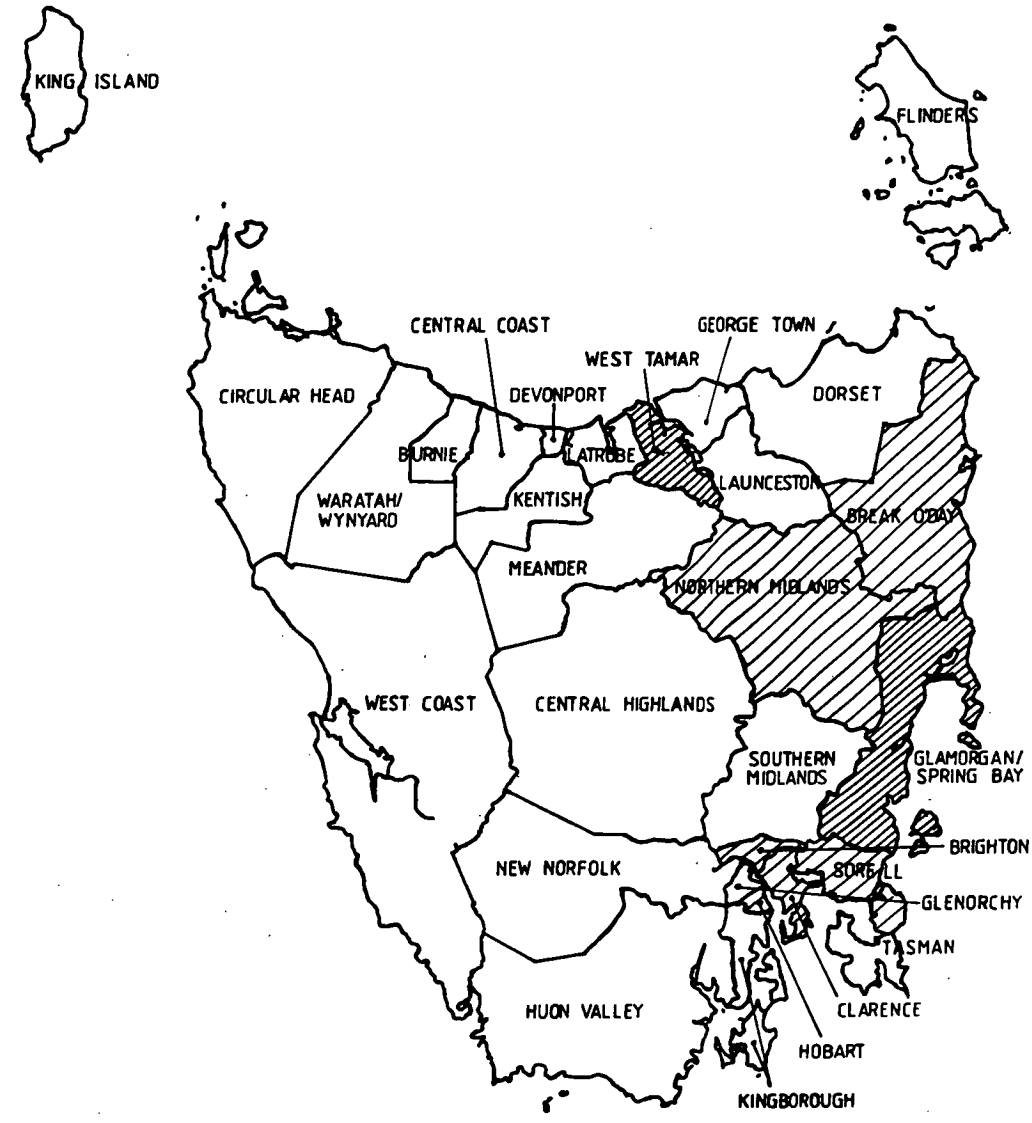
Tasmania is well endowed with water resources. It benefits from receiving 12% of Australia's total rainfall whilst having a population of only about 3% of the national total. The highest runoff occurs in the wilderness areas of the western mountainous regions of Tasmania whereas the northern and eastern areas are considerably drier and suffer frequently from drought. Some of the severest have occurred in the last few years and water shortages have occurred in towns situated on the east coast during the holiday season. As a consequence, these dry regions have been the subject of a number of feasibility studies to install potable water irrigation schemes (Brown et al. 1983: 232).

Up until the early 1980s, no domestic reclaimed water reuse scheme was known to be operating in Tasmania (GHD 1983: 30).

In 1993, Hon John Cleary, the Tasmanian Minister for the Environment made a public statement, 'that by December 1997 there will be no discharge of effluent from sewage lagoons into inland waters unless councils have demonstrated that land application is not feasible' (DELM 1994: 5). With this challenge, municipal STPs are looking for ways to profitably 'dispose' of their effluent to land. Therefore, both STP operators and potential clients are looking to benefit from establishing well managed wastewater reuse schemes.

Since John Cleary's press release, a significant number of councils have moved to implement TSE reuse. To this end, the Department of Environment and Land Management (DELM) has compiled a set of guidelines for wastewater reuse (Bell 1993). Nevertheless, John Nolan (1993: 5) made the comment that, 'Due to the relatively high rainfall in Tasmania, 'total' reuse may not be practical as the winter storage, and run-off collection systems will be very large and expensive'. Despite this, there is still room for growth. At present two municipal reuse schemes are in operation in Tasmania (Map 3.2), one at Riverside Golf Course in the West Tamar Shire and one in Swansea which uses effluent for crop and pasture irrigation (LPH Pty Ltd nd: 17), in the municipality of Glamorgan. Specifically, Hobart City, Clarence, Sorell, Brighton, Glamorgan/Spring Bay, Break O'Day, Northern Midlands and West Tamar councils are either reusing TSE or investigating its use (Howett, S. DELM 1996, pers. comm., 15 Mar.). In particular, Clarence Council has recently proposed a wastewater reuse scheme in the Seven Mile Beach area involving up to 820 ML/a for silviculture and golf course irrigation (Sann 1995). Sorell Council has also been seriously considering embarking on an effluent reuse scheme for agriculture and golf course irrigation (Sorell Public Meeting 22/2/1995).

The wastewater is sought largely for agricultural and greenspace irrigation and the majority of the available wastewater supplies is well suited to land application. The greatest hindrance to implementing reuse schemes appears to be the high capital cost of installing the reticulation and pumping systems rather than public acceptance.



Councils proposing reuse schemes

Councils currently supplying TSE for reuse

MAP 3.2 - Tasmanian Municipal Councils Currently Supplying or Proposing to Supply TSE for Land Based Reuse

CHAPTER 4

HEALTH CONCERNS ASSOCIATED WITH WASTEWATER REUSE - A LITERATURE REVIEW

4.1 Introduction

The main reservation expressed against the recycling of wastewater has been a concern over the public health risks involved in its end use. The issues of legal liability, public image and social responsibility are of importance to both the supplier and the recycler of effluent, particularly when the public has access to irrigated areas or are likely come into contact with the effluent.

With the rise of the modern environmental movement in the 1960s, government agencies at all levels, particularly in the USA, have been encouraged to set specific and enforceable standards in order to protect public health and the environment against toxic and carcinogenic industrial chemicals (Ruckelshaus 1985: 105-6). Stringent standards were prescribed in the 1970s in an attempt to provide a 'risk-free' environment. Not long after this, agencies began to strike insurmountable problems, particularly with the less known and less obvious pollutants. Scientific databases which provided information on these pollutants and their effects in the environment were grossly inadequate in dealing with the rapidly increasing number of new industrial chemicals. The required information detailing the maximum acceptable levels of a pollutant in the environment which would provide this 'safe' environment was simply not available. In addition, agencies were becoming more aware that a 'risk-free' environment was an impossible ideal demanded by the public and its politicians within a largely imperfect world. In particular, the United States Environment Protection Agency (USEPA) was faced with the dilemma of having to make immediate policy decisions without the necessary information to make such decisions (Ruckelshaus 1985: 109).

In an attempt to deal with this conundrum, a shift in thinking took place from 'guaranteeing certainty' to 'managing uncertainty'. Out of practical necessity, managing risks became the new way of addressing environmental and public health issues. Policy formulation has developed in countries such as the United States and more recently in Australia into a 'process of risk acceptance' that can be divided into

two areas: 'risk assessment' and 'risk management'[1]. Risk assessment was developed as a tool to assist in the provision of either qualitative or quantitative predictions of an adverse event occurring given certain conditions. It seeks to answer the question of, 'What is the risk?' and therefore tends to be an objective and scientific process (Ruckelshaus 1985: 109).

Once an estimate of the risk is made, regulatory authorities are faced with what to do with it. Difficult questions confront them, such as: 'Is this an acceptable risk?'; 'What is an acceptable risk?'; 'Who determines what is an acceptable risk?'; and 'Do the benefits of a potentially hazardous practice outweigh the cost both in social and financial terms?'. Once these questions have been answered then the final question, 'What must be done to maintain this acceptable risk?' must be addressed. This is the world of risk management: the determining of what is an acceptable risk and managing that risk. In the area of wastewater reuse, agencies initially managed risk by developing enforceable regulations, now there is more of a trend towards producing guidelines.

The USEPA defines risk management as 'the process of evaluating alternative regulatory and non-regulatory responses to risk and selecting among them. The selection process necessarily requires the consideration of legal, economic and social factors' (USEPA 1988). Risk management, unlike risk assessment, becomes a very complex and unpredictable process, involving the assessment of social values and perceptions, public fears, and vested interests. Jocelyn Auer (1989: 441) quotes W.D. Rowe (1977) as saying that, 'the subjective perception of risk is the basis of risk acceptance regardless of the objective or quantified evaluation'. Thus to resolve conflicting points of view, which are based to some extent on subjective feelings, risk managers must handle conflicts with a high degree of care and wisdom by establishing a clear process for discussion of value differences and providing a simple and clear presentation of the facts in order to avoid unnecessary polarisation amongst interest groups. Douglas and Wildavsky (1983) developed a concept called 'a cultural theory of risk perception' which has to do with peoples' views of the environment being socially shaped by moral, economic, political and other factors. The approach of interpreting community involvement as a process of handing down the 'right' information to the 'masses' by those who 'know' is seen as neither useful nor tenable.

[1] Risk managers may argue that risk assessment is part of risk management but for clarity of explanation they are dealt with separately here.

A way must be provided which acknowledges the validity of the 'lay' position as well as the 'scientific one' (Auer 1989: 442). Therefore, regulatory bodies can no longer afford to make arbitrary decisions in a sheltered and clinical environment if the public is to have confidence in its policy makers. As a result, risk management has begun to involve all sectors of society, not just the 'experts' (Ruckelshaus 1985: 116).

Figure 4.1 seeks to illustrate the complexity of the process of risk acceptance. In a democratic society, the public has input to the policy makers via elected members of government who then create the laws within which all sectors of society are bound for the good of society and its environment. In addition, research institutions and the scientific community play a role in providing objective and factual public health information to policy makers, the public and industry.

Public acceptance of particular risks is based on the its values and their perceptions of what constitutes a hazard and how this might affect it. Often these values and perceptions can be misguided. However, they are not static and therefore public education by policy makers and research institutions plays a vital role in risk acceptance so that public acceptance is based, as much as possible, on sound information.

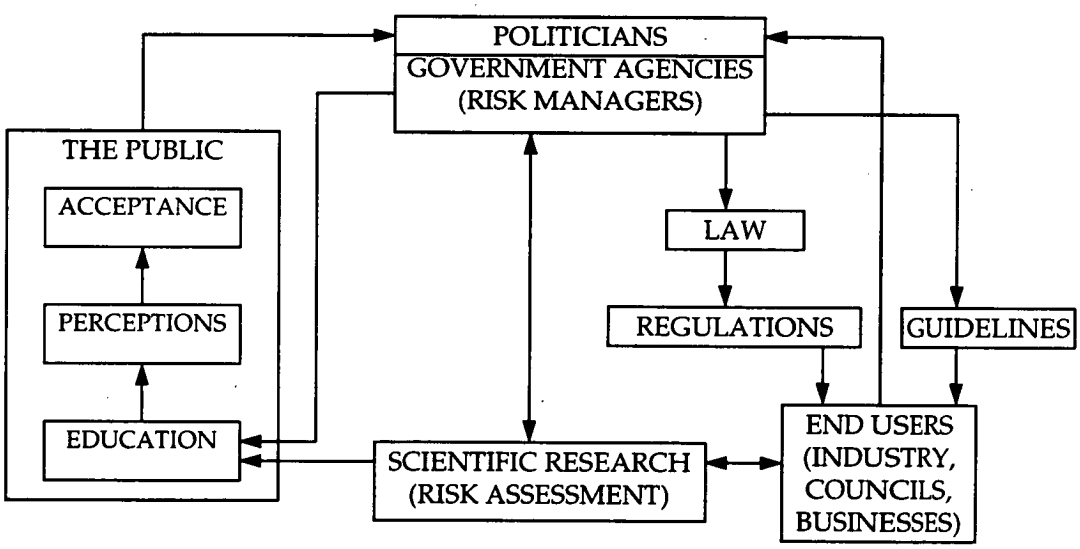


FIGURE 4.1 Process and results of risk acceptance

These principles of risk assessment and risk management have been applied to the area of recycling wastewater. For wastewater to be responsibly and safely used, a careful assessment of the risks involved is necessary (Shahalam & Mansour 1989: 148). Pathogenic viruses, bacteria, protozoa and helminths that are excreted from the bodies

of infected individuals may infect exposed groups in a reuse situation by several routes:

- via the mouth, for example, by eating contaminated vegetables;
- via the skin which might come into contact with effluent affected soil as in the case of hookworm or through broken skin; and,
- by inhalation of aerosols.

In addition, other hazards, such as heavy metals and organic chemicals can be applied to land from effluent and sludge which are toxic or carcinogenic to humans, animals and plants and therefore pose a health risk in a reuse application (Sagik et al. 1979: 241). The chemical and microbial quality of sludges and effluents from treatment plants are dependent on the nature of the incoming raw sewage and the treatment process employed. With domestic effluent, risks are higher for pathogenic infection than by toxins because the industrial waste contribution is usually small compared to the household and commercial contribution. This thesis focuses on the health issues in relation to municipal domestic wastewater reuse only and therefore treats pathogens as the main hazard.

Even though there are real and assessable risks present, it is contended that these risks can be managed to relatively insignificant levels, and can be regulated by several factors:

- Sewage treatment technology. Improvements in this technology can now permit complete renovation of wastewater allowing for a comprehensive variety of very low-risk end uses. Factors which affect the quality of reclaimed water are: the quality of the source water; the degree of sewage treatment; the treatment reliability and the distribution system design and operation (Crook 1994: 58);
- Community sanitation and hygiene practices. Poor hygiene and a lack of provision of sewerage result in high prevalences of diarrhoeal disease and intestinal parasites;
- The concentration of pathogens in sewage which is influenced by the age, health and immunity of the *contributing* population and by the season of the year (Sagik et al. 1979: 242);
- Maintaining the health and immunity of the *exposed* members of the community;

- The means of application of the effluent in a reuse scheme.

Despite the ability to be able to effectively regulate the risks involved in effluent reuse, the lack of empirical evidence on the ill-effects on human health and the environment, and the social taboo of modern and healthy societies in viewing sewage as a waste, have discouraged full acceptance of reuse (GHD 1983: 5). Therefore, not only must informed risk assessment and technical planning be undertaken for the successful adoption of reuse schemes, but the underpinning attitudes and perceptions of social institutions and the public towards reuse must be well understood and managed effectively.

4.2 Human Health Risk Management

It is important to note that there are few (if any) actions in life that are risk free. People take risks if they judge that the benefit to be gained outweighs the risk involved. Usually an individual makes this judgment instinctively, based on past experience. Nevertheless, for health authorities to adopt this attitude would be seen by most as immoral and probably illegal. Thus a process of public consultation of risk acceptability needs to take place or at the very least, authorities need to demonstrate responsibility and objectivity in making these decisions (Greene 1982: 152).

Based on American death risk data from 1950 to 1975, Greene (1982: 159) makes the comment that the public will tolerate deaths from voluntary risks much more readily than those that result from involuntary acts. A chosen lifestyle that revolves around motor vehicle transport and smoking indicates a great tolerance of voluntary risks. For example, the death risk per person of lung cancer for male smokers between the ages of 30–75 was 1.6×10^{-3} during the period from 1951 to 1960 whereas dying from a waterborne disease only carried a risk of $<5 \times 10^{-7}$ in 1973.

To provide an idea of the risks involved in public access effluent reuse, Rose and Gerba (1991b: 2091, 2097) estimated that the risk of a viral or parasitic infection from drinking 100 mL of secondarily treated and disinfected reclaimed water from Arizona or Florida sewage treatment plants that is deemed suitable for restricted public access irrigation ranges from 1 in 500 to 1 in 50 000. Once infected, the risk of death is <1% resulting in an overall risk of fatality as 1 in 50 000 to 1 in 5 000 000. These risks are

small when compared to the lifetime risk for motorists of a fatal accident of 1 in 120.[2] Nevertheless, the former risk may be considered to be an involuntary one and the latter voluntary.

As a result, many golf courses in the United States have been hesitant to use reclaimed wastewater because of potential liability and public perception. Nevertheless, in some states, such as California, legislative declarations enforce the use of non-potable water for non-potable uses as long as economic, health protection and environmental conditions can be met. To use potable water for non-potable uses, in the case of golf courses, is seen as a waste that can no longer be tolerated (Thomas 1994: 94).

Risks can be minimised by technical and social controls but these always come with a price that a society must be willing to bear (Greene 1982: 151-2). How much cost a society is willing to bear is dependant on community attitudes and values. For example, one might find considerable resistance from a community for the implementation of more stringent motor vehicle safety standards by reducing the speed limit. This may be interpreted as an impingement on a higher perceived value of a personal freedom. It is not until a change in desired lifestyle takes place that the degree of public acceptance will become flexible. This change is being demonstrated in the case of smoking where it has become less demanded as a right to personal freedom in a context of a more health conscious society that now sees passive smoking in public buildings as an intolerable health risk. One therefore must be sensitive to these community values in order to set risk acceptability targets. Researchers have tried to develop a mathematical 'quality of life' index that reflects our aggregate needs, desires, and expectations and reflects some sort of community consensus in an attempt to provide a more objective analysis (Greene 1982: 161). Whether or not this is a realistic way forward is debatable.

Interestingly, when the potentially exposed groups are themselves involved in the decision making process and are forced to confront tradeoffs entailed in risk management, it is possible for them to think rationally and come up with helpful ideas once they have overcome their initial fears (Ruckelshaus 1985: 114-5).

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[2] This figure is based on the 1993 Australian Bureau of Statistics death rate due to a motor vehicle accident as 11 per 100 000 population multiplied by 75 years (ABS 1993).

4.2.1 Attitudes and Perceptions of Risk Managers

From the 1840s to the 1900s, public health concerns and environmental degradation issues associated with discharging wastewater into the environment prompted development of methods for treatment of sewage which consequently helped to sharply reduce death rates. Originally disposal was by means of land based irrigation or intermittent land filtration. In Europe and in the USA, growing towns put increased pressure on these systems and a trend away from them began in the late 1800s. Other methods of treatment that would accelerate the forces of nature under controlled conditions were developed, allowing smaller land areas to be utilised. Sedimentation, chemical precipitation and screening were developed for land application systems. Later trickling filters and activated sludge units were added. Such systems have now become so fundamental that they are now referred to as 'conventional' treatment systems. Land treatment gave way to partial treatment and discharge into large waterways by the 1920s (Forster & Southgate 1984: 400; Metcalf & Eddy 1991: 122).

Agencies responsible for water and wastewater treatment have tended to be biased against land application due to the historical evolution of wastewater treatment resulting from historical epidemics due to poor sanitation. The greatest resistance came from engineering and water professions who attempted to provide pristine water supplies in the interests of public health by ensuring the protection of surface and groundwater supplies. In addition, sanitary engineers resisted sewage irrigation on health grounds and for aesthetic reasons (Nichols 1988: 1931). Waste has been considered a disposal problem and not a resource recovery problem. For example, by 1959, only 2% of communities with populations over 5000 in the then Federal Republic of Germany partially or wholly used sewage on land (Müller 1969: 24). Waste treatment texts have largely ignored land application or just briefly mentioned it and frequently councils have underestimated community acceptance of land application (Forster & Southgate 1984: 401). These views have now been criticised as perhaps idealistic and overly conservative.

Water planners are now turning to reuse as a technique to primarily augment or conserve existing water supplies where widespread contamination of water supplies, droughts and population pressures in arid and semi-arid areas have been occurring. For some engineers the shift from a disposal ethic to a conservation ethic has far reaching implications for water and wastewater industries that traditionally had little

to do with each other. Wastewater is now being seen as a valuable resource and water and wastewater industries are finding themselves working together as co-stewards.[3] (Nichols 1988: 1931).

With regard to direct and indirect potable reuse, considerable controversy has arisen because of the higher degree of human contact involved. This issue has served to polarise water professionals into two opposing camps. For the defence, it is argued that there is no such thing as 'perfectly' pure water, whereas, potable reuse technology can provide multiple protection barriers enabling a higher degree of control and often a higher degree of water quality than from natural sources. In the other camp, non-potable reuse is applauded as necessary, but not so potable reuse. They feel that it would be difficult to establish the safety of direct potable reuse over a lifetime of public ingestion and public acceptance would be hard won, although there are some exceptions where the public has accepted potable reuse in situations where water supplies are critical (Section 3.2.8). An example of this is the reclaimed water aquifer recharge plant in El Paso, Texas, that treats the water to a potable standard. The planning involved a citizen's advisory committee and public meetings and it has received overwhelming support from the public.

Municipal wastewater reuse for any purpose is still prohibited in places where ample supplies of fresh water are available. In 1986, eight states in the USA had prohibited wastewater reuse for this reason.

Even though some in the engineering and health professions believe that the controversies over the health issue may never be resolved (Nichols 1988: 1934-5) considerable proliferation of wastewater reuse schemes, particularly in developed countries, confirms a tremendous shift among water and wastewater managers and public health authorities towards not only supporting municipal reuse but to active promotion of the practice.

[3] It is of interest to note that the Australian Water and Wastewater Association provides a cohesion of the two fields of expertise.

4.2.2 Public Acceptance

4.2.2.1 Public Attitudes and Perceptions

One major barrier to widespread reuse of domestic wastewater is poor public perception. Perceived health risks from contacting effluent in reuse operations poses the greatest hindrance to public acceptance of treated sewage effluent reuse (Schlafrig & Anderson 1992: 4).

Likely factors which have led to lack of public support for reuse schemes have been:

- the lack of public awareness and responsibility with regard to the fate of their domestic waste;
- confusion often displayed by the scientific community over the health issues;
- public phobia associated with faecal matter and the fear of coming into contact with it;
- lack of opportunity for public involvement in the risk acceptance process;
- perceived excessive financial outlay required to establish reuse schemes; and
- other social and religious factors.

Conversely, public support for reuse schemes has come from:

- a growing public concern for the environment;
- informed and effective public education on the health risks;
- opportunities for public participation in risk acceptance; and
- increasing water shortages

Firstly, individual responsibility over what happens to domestic wastewater and its impact on the environment has now been transferred to the public utilities that treat the waste. This has bred an 'out of sight - out of mind' mentality to the extent that most people have no idea what happens to their waste once it goes down the plug hole. Added to this, a consumerist 'once-through' attitude has been prevalent in young developed nations such as the United States and Australia which makes waste recycling a largely foreign and repugnant concept (Schlafrig & Anderson 1992: 4).

Secondly, confusion or conflicting points of view within the scientific community on the actual public health risks of wastewater reuse may affect public confidence in reuse

schemes. Renewed debate within the scientific community, particularly over groundwater recharge has taken place in the USA (Pinholster 1995: 174A). One study, in California, has shown that over a 10 year period, secondary level treatment plants removed 99.8% of viruses (Yanko, 1993). But another (Powelson et al. 1993) was less conclusive, saying that virus removal in soils depends on the virus and on environmental conditions, where removal varied from 37 to 99.7%. Conflicting or unqualified statements have also generated confusion over the issue. E. Hartling, a water recycling coordinator, stated that, 'It (virus) does not survive long periods (in an aquifer) because it has no opportunity to replicate itself', whereas B. Hultquist, a sanitary engineer stated that, 'viruses don't live very long, but it is all relative because they can live in excess of a year.' (Pinholster 1995: 177A). The public will need some consensus of opinion based on a more robust understanding of what hazards are present in the effluent and what the risks associated with them are before they can have confidence in reuse schemes (Cort 1987: 38).

Thirdly, faecal phobia and aesthetics also play an important role in public acceptance as people are unlikely to use reclaimed water if it looks or smells 'polluted' (Wilkins & Anderson 1991: 32). The public has a preconceived notion that wastewater is 'dirty' and 'unhealthy' (Rodie 1994: 265). One engineer commented at the AWWA 15th Federal Convention, 'When I show people a sample of treated wastewater, they are always amazed ... they always have the concept of raw sewage in mind' (Swinton 1993: 18). To make wastewater 'palatable' and acceptable to the public, often the issue surrounds the 'saleability' of the terms used. The choice of words in public meetings such as 'reclaimed water' or 'effluent' is better than saying 'wastewater' (Gill & Rainville 1994: 48).

Public perception of waterborne disease may also lag well behind current facts and recent data about morbidity and mortality rates. There is still a public phobia about faecal matter that lends itself to seeing faecal disease as less acceptable than other forms of disease (Greene 1982: 164). Therefore, in regard to this issue, risk managers are faced with the difficult and complex task of identifying public perceptions and facing the challenge of whether or not to direct it from a 'biased' and 'mythical' foundation to a more 'equitable' and 'factual' foundation. And if so - how?

Fourthly, thorough community consultation and participation tends to alleviate resistance to any proposal that may be perceived as a health threat. The following case

in Port Adelaide serves to illustrate this point. A Public Health Department report stated that a particular industrial practice provided no scientific basis for causing concern, which did not pacify the local community's fears. A process of dialogue and mutual respect of other views, despite continuing differences in perception, resulted in better cooperation between 'officials' and the 'community groups' (Auer 1989: 446). The conclusion was made that the risk acceptance process should ensure representation of community groups and an effective community voice. An attitude change by risk managers was also required which recognised that what is 'safe' is socially determined and that the community's perceptions need to be acknowledged even if they are at variance with the officials of the departments of public health. As a consequence of this case study, the government undertook a more proactive role in community consultation.

Forster and Southgate (1984: 399) also commented that unless political, institutional and social constraints are considered, any reclaimed water project may fail regardless of its technical, scientific and economic feasibility. Despite evidence that suggests the existence of minimal pathogen hazards associated with well managed land application schemes, the public intuitively suspects that they are unsafe. However, attitudinal changes can take place when the public is involved in the decision-making process.

Finally, important sociocultural and religious factors may also affect the acceptability of a reuse scheme. In China, where raw excreta in agriculture has been accepted as the norm over centuries, pretreatment of wastewater may be seen as unnecessary. Conversely, in some cultures, contact with faeces is prohibited. Nevertheless, where water is used for religious ceremonies, most religious authorities have accepted the use of well purified, treated wastewater for reuse. Often the readiness of people to accept new ideas and changes in traditional values is underestimated if they have nothing to lose by it (WHO 1989: 20).

Possibly, one of the biggest misconceptions has been that the public is against non-potable reuse. The rise of the modern environmental movement has largely influenced a change in this attitude by promoting sustainable development and the need therefore to conserve precious resources. Loretta Lohman, a research social scientist in Colorado stated:

> It is a myth that the public will not accept it. All surveys show that there is substantial public support for reuse right up to direct contact reuse and, with

proper education, the public will even support direct potable reuse (Nichols 1988: 1931).

Therefore, when communities are faced with increasing costs to supply water, watershed protection plans, and public concern for water conservation, effluent can provide a solution that is often acceptable to the public.

Different groups within societies have also been shown to vary in their acceptance of reuse schemes. Women tend to be less accepting of land treatment than men due to the perceived greater health risk and most new technologies are accepted less readily by older people. Formal education and exposure to reuse schemes positively correlates with acceptance. Farmers may be pressured by the need for short term economic gain and therefore may not want to make the long term investment required for a successful land application scheme, or they may see themselves as guardians of nature for the benefit of future generations and are therefore willing to invest in a reuse scheme. Alternatively, they may see municipal waste as an urban problem and not their own (Forster & Southgate 1984: 400).

4.2.2.1.1 Studies of Public Acceptance

Studies show that the degree of acceptance is related to the type of use proposed, particularly with regard to the degree of human contact. Non-potable uses are generally favoured but reuse for swimming or drinking, even recharging potable aquifers with effluent, meets obvious resistance (Cort 1987: 38, Pinholster 1995: 175A).

Bruvold (1988) conducted a review of seven surveys in the USA on public opinion of water reuse schemes. These surveys covered a total sample population of around 3 500 respondents. Each survey had differing lists of reuse options upon which acceptance levels were graded. He conducted two survey procedures of public reuse that provided two different responses. The first procedure was to ask the respondent whether or not they would, in general or in principle, view a particular reuse option as acceptable. From this review, Bruvold (1988: 46) demonstrated that public acceptance was directly related to the degree of public contact with the effluent without reference to the quality of that effluent. Therefore, reclaimed water to be used for drinking purposes meets the highest resistance (64% opposed) whereas restricted golf course irrigation was very low (3% opposed). Bruvold (1988: 46) found this to be such a stable finding across the available literature that the information can be used for policy formulation. He suggested that, when wastewater reuse schemes are being introduced

into a new area, public acceptance would be more easily encouraged when low contact schemes are introduced first and higher level contact schemes are introduced later. A University of California study also revealed that citizens generally favour reuse for irrigation of golf courses, play grounds and lawns, but not for drinking (Cort 1987: 38).

The second survey procedure, which is probably the more important one, he termed as surveys of 'salient use' options. That is, surveys which ask the respondent whether or not they would be opposed to a particular reuse scheme being introduced into their neighbourhood in the near future. The responses to these type of surveys were found to be slightly different to the general option survey. Analyses of the results of this type of survey revealed that a proposed reuse scheme would be accepted not based just on the degree of contact but also on four other factors expressed in terms of the following questions. Does the scheme conserve water? Does it enhance the environment? Are the treatment costs affordable? And, are the costs of distribution affordable?

As a result of these surveys, wastewater to be used for swimming and orchard irrigation had a higher degree of opposition (66%) than for drinking purposes (64%). Ocean discharge had 71% opposition. Opposition to irrigation of recreational parks rose from 3 to 26% when comparing an 'in principle' scheme with a proposed scheme. It is of interest to note, and very important to realise, that public opinion does not always match reality. For example, a water authority might calculate that ocean discharge is the cheapest, safest and most environmentally benign option but the public might not perceive this to be the case. Therefore, in planning to introduce a reuse scheme, it may be well worthwhile to survey the community on its acceptance of a range of reuse options.

In Australia, most public acceptance surveys have focused on non-potable domestic reuse schemes. The first conducted in Australia was by the NSW Public Works Department. A domestic reuse demonstration pilot scheme was trialed in 17 residences in Shoalhaven Heads in 1989-1991 to enable an objective assessment of community attitudes to domestic reuse (Wilkins 1992: 1). The project was quite successful in that a 40% reduction in the use of potable water took place in these residences. The reasons for its success in terms of public acceptance were:

1. supplying the effluent free of charge;
2. the high degree of appropriate public relations;
3. the high quality of the effluent supplied (0 faecal coliform/100 mL); and

4. people genuinely wanted to play a role in environmental conservation.

The public consultation process started right from the beginning of the project with meetings explaining the objectives and benefits of the scheme, a public inspection of the wastewater treatment plant, an information newsletter, regular update meetings with the users and the employment of a government representative to be available to the public and visit the residences for informal chats. It was found that people responded well to the personal approach. The researchers were realistic with regard to the health risks by explaining the need for caution to those who did express concern. They held the view that public relations demands patience, honesty and openness at all times in order for a proposed scheme to be accepted, particularly for this degree of human contact (Wilkins & Anderson 1991; Wilkins 1992: 6).

Organisers of this scheme visited similar schemes in urban California, Florida and Arizona and found that public acceptance was favourable towards reuse schemes that offered cheaper, reliable wastewater where the potable supplies were limited.

The NHMRC et al. (1996: 3, 4) guidelines confirm the above conclusions, citing that public acceptance is a function of: cost, degree of human contact, health, environment, degree of effluent treatment, distribution costs, conservation and community expectations. The guidelines also express that a high degree of public acceptance is essential for projects including public contact.

With regard to public acceptance of potable reuse in Australia, the Noosa Shire Council in South East Queensland conducted a community consultation with more than 1 500 households responding to a survey. Thirty nine percent of respondents favoured direct potable reuse which was the highest vote, 22% supported agricultural irrigation whilst 32% favoured discharge into an inland waterway (NSW RWCC 1995: 5).

4.2.2.2 Public Education and Risk Communication

Public education is crucial in dealing with potential misconceptions or unrealistic fears of wastewater reuse on land accessible to the public (Schlafrig & Anderson 1992: 4). Accurate and understandable information about a proposed scheme is important in gaining public acceptance. Joyce Wegner-Gwidt, (Cort 1987) of the Irvine Ranch Water District stated that, 'The key to public acceptance is a very broad public

District stated that, 'The key to public acceptance is a very broad public relations and education program aimed at all parts of the community - starting with fourth grade'.

A reuse scheme in the USA, called Project Apricot, in Florida, made the following points in order to educate people in use treated domestic effluent for non-potable residential purposes. It had been necessary to explain the benefits of water reuse and ease the concerns of customers who may have misconceptions regarding the safety of wastewater reuse. This requires an effective public relations program. The City (council) seeks to ensure wide dissemination of factual information via community meetings, direct mail and door-to-door contact, media relations, presentations to clubs and schools, conducting tours of the water treatment facility, demonstration schemes and seeking resident permission as indicated via a petition (Boyd 1992: 5). In 1992, as a result of community consultation and education, reclaimed water had been successfully supplied to 3 000 residences. On average 79% of residents had signed for reclaimed water connection and more appeared to desire connection once the service became available.

Forster and Southgate (1984: 399, 402) also made similar conclusions regarding the procedure for an effective education program noting that field demonstration plots were found to be among the more effective educational methods.

In their report, Gutteridge, Haskins and Davey Pty Ltd (GHD 1983: 39) indicated that 'the public need to become aware of the potential savings and benefits of recycling wastewater, and importantly, of its safety'. They recommended the formation of reclaimed water committees in the various states to conduct seminars, use demonstration projects, obtain appropriate media cooperation and encourage planning for reuse in water and sewerage scheme planning. Since then the NSW Recycled Water Coordination Committee has been formed with similar groups appearing in other states.

4.2.3 Legal Liability

In Australia, the use of reclaimed water is governed by the States and Territories where specific statutory obligations come under health, environmental and agricultural legislation. In particular, STP operators and end-users may be liable

under common law and under the Trade Practices Act for the use of wastewater that causes harm (NHMRC et al. 1996: 4).

A number of councils wanting to recycle effluent have discovered that their insurers treat effluent reuse as a polluting activity and as such the practice cannot be insured because one cannot insure for personal injury against breach of statute (NSW RWCC 1996: 3). To overcome this problem, Shires and Local Government Associations have set up a special committee to investigate their options. One being a mutual protection fund available to those who join the scheme.

Risk managers (NHMRC et al. 1996: 4) also recommend courses of action which can minimise exposure to legal and financial risk, such as:

- backup systems to ensure effluent is not transported to a reuse scheme in the event of STP failure;
- proper training of staff and contractors in the understanding of any legal requirements and risks;
- well archived records of reclaimed water use;
- provision of effective eduction of consumers on conditions of use of the effluent;
- implementation of a quality assurance program; and
- clear stipulation of the responsibilities of the supplier and user along with appropriate contractual arrangements.

With regard to legal liability of golf courses reusing effluent in the US, discussion of legal liability for injury caused is still hypothetical since there seems to be no reported case of injury caused by wastewater reuse (Thomas 1994: 99; Rodie 1994: 265). Principles of general tort and contract law covering aspects of neglect, implied warranty of the supplier, product liability of the effluent and emotional distress still apply, although these laws have yet to be applied.

4.3 Human Health Risk Assessment

4.3.1 Introduction to Health Risk Assessment

There has been a dramatic emphasis, particularly portrayed by the western press, that this generation is confronted on every side with significant health risks, much more so than in past, as we continually learn about new hazards. Even though health risks change, mainly due to lifestyles changes, risks have always been present. There is a public perception that exposure to a certain risk means a 100% likelihood of a disastrous effect. This is frankly not true. Therefore, an essential ingredient in risk assessment is the concept of probability. For example, not all smokers develop cancer and not all drinkers of wastewater effluent will develop a gastrointestinal disease. There is a quantifiable relationship between exposure to a hazard and the potency of the hazard itself, whereby:

Risk = Hazard x Exposure (Maynard 1993).

Over the last twenty years a fairly universal protocol has been established to attempt to provide a definitive and robust process by which quantifiable risks can be attributed to human exposure to low doses of hazardous materials under particular conditions. Researchers, such as, Dr J. Rose and Dr C. Gerba have coined this process 'Quantifiable Risk Assessment' or QRA (Rose 1993: 1; Gerba et al. 1996: 254). This process has the advantage that it can be applied to any sort of hazard whether it be a pathogen, carcinogen or a toxicant. The QRA process involves four steps as follows (Rose 1993: 1):

1. Hazard Identification - seeks to identify the agent which causes a specific health effect and to identify the adverse health effect it causes.

2. Exposure Assessment - involves determining the actual dose of the hazard received by a person during a specified period of exposure. This period of exposure is defined by the frequency, duration, intensity and mode of exposure to a particular hazard.

3. Dose Response Assessment - is the determination of a mathematical relationship that predicts the likelihood of an adverse effect from a particular dose ingested. These are described as probability functions.

4. Risk Characterisation - is the end result of the dose response calculation that expresses the risk of an adverse effect from exposure to a particular hazard and is expressed as a probability.

Before describing the mechanics of QRA, different measures of risk are used in the field of risk management that need definition.

A 'potential' risk (WHO 1989: 29) refers to the possibility of developing a disease based on measured levels of pathogens in the wastewater and on the treated vegetation. The potential for disease is present even if no one who is exposed incurs an illness. Management of a potential risk therefore places great emphasis on microbiological monitoring of wastewater and vegetation, and relies on specifying removal rates to ensure the absence of these 'potential' risks. There is thought to be a potential risk of developing a disease even if no case of disease is caused after detecting pathogens in the effluent or on treated vegetation.

'Actual' or 'attributable' risks (WHO 1989: 29) are terms which epidemiologists use to refer to the chance of an individual contracting a disease as a result of a definite and specific exposure to a hazard over a certain time period. This is the domain of those who seek to quantify actual probabilities of risk under prescribed conditions. This is the risk that the QRA seeks to determine.

A potential risk may only become an actual risk when conditions of pathogen survival, minimum infective dose, human host behaviour and immunity levels are favourable to disease occurring (WHO 1989: 29). Therefore, for a potential risk to become an actual risk, all the following conditions must be met (WHO 1989: 30):

1. either an infective dose of an excreted pathogen reaches the field or pond, or the pathogen multiplies in the field or pond to form an infective dose;
2. the infective dose reaches the human host;
3. the host becomes infected; and
4. the infection causes disease or further transmission.

The same pathogen may have access to the human host by paths other than from a wastewater reuse scheme. It is therefore important to know which pathway poses the greatest risk. 'Attributable' or 'excess' risk, refers to the risk of infection by one path which may be different to the risk of infection by another path. Usually this involves the comparison of a control population not exposed to a specific pathway with a group that is so exposed. This control population may be exposed by another route of infection, for example, by contamination of a domestic water supply (WHO 1989: 29).

'Relative risk' (WHO 1989: 29) is the ratio of the risk estimate for an exposed group to that of a non-exposed or control group and represents the number of times a disease is more or less likely to occur in the exposed group as compared with the control group.

4.3.2 Hazard Identification

This first step of risk assessment attempts to identify and enumerate pathogens in TSE after leaving the STP or before it is recycled. Many pathogens typically found in sewage have been identified and are neatly divided into four main groups: bacteria, viruses, protozoa (parasites) and helminths.

4.3.2.1 Pathogen Characteristics

A list of infectious agents that are potentially present in raw domestic sewage and which are of major concern has been compiled from several sources in Table 4.1.

Organism	*Disease*	*Symptoms of disease*
Bacteria		
Campylobacter jejuni	Gastroenteritis	Diarrhoea, vomiting and abdominal pain
Escherichia coli (enteropathogenic, enterotoxigenic, enteroinvasive, enteroaggregative, diffusely-adhering, enterohaemorrhagic [EHEC])[b]	Gastroenteritis	Acute diarrhoea
Legionella pneumophila	Legionellosis	Acute respiratory illness
Leptospira (150 spp.)	Leptospirosis	Jaundice, fever (Weil's disease), skin rashes, meningism, headaches, chills, malaise, vomiting, aches and conjunctivitis.
Salmonella paratyphi (3 spp.)	Paratyphoid fever	acute enteric infection, fever, spleen enlargement, diarrhoea and lymphoid involvement.
Salmonella typhi	Typhoid fever	High fever, diarrhoea, ulceration of small intestine
Salmonella (~ 1700spp.)	Salmonellosis	Food poisoning
Shigella (4 spp.)	Shigellosis	Bacillary dysentery
Vibrio cholerae	Cholera	Extremely heavy diarrhoea, vomiting, acidosis, dehydration and circulatory collapse
Yersinia enterolitica	Yersinosis	Diarrhoea, mesenteric lymphadenitis and abdominal pain
Y. pseudotuberculosis	Yersinosis	Diarrhoea, mesenteric lymphadenitis and abdominal pain
Viruses		
Adenoviruses (31 types)	Respiratory disease	Various
Enteroviruses (67 types, e.g., polio, echo and coxsackie viruses)	Gastroenteritis, heart anomalies, meningitis	Various
Hepatitis A	Infectious hepatitis	Jaudice, fever
Norwalk agent	Gastroenteritis	Vomiting, diarrhoea, abdominal pain and headaches.
Reovirus	Gastroenteritis	
Rotavirus	Gastroenteritis	
Papovirus		Associated with PML (Progressive multifocal leukoencephalopathy) and immunosuppression[c]
Astrovirus	Gastroenteritis	
Calicivirus	Gastroenteritis	
Coronavirus	Gastroenteritis	
Protozoa		
Balantidium coli	Balantidiasis	Diarrhoea, dysentery
Cryptosporidium parvum	Cryptosporidiosis	Diarrhoea
Entamoeba histolytica	Amebiasis (amoebic dysentery)	Prolonged diarrhoea with bleeding, abscesses of the liver and small intestine
Giardia lanblia	Giardiasis	Mild to severe diarrhoea with bleeding, abscesses of the liver and small intestine
Helminths[a]		
Ascaris lumbricoides	Ascariasis	Roundworm infestation
Enterobius vermicularis	Enterobiasis	Pinworm
Necator americanus	Necatoriasis	Hookworm
Ancylostoma duodenale	Ancylostomiasis	Hookworm
Fasciola haptica	Fascioliasis	Sheep liver fluke
Strongyloides stercoralis	Strongyloidiasis	Threadworm
Hymenolepis nana	Hymenolepiasis	Dwarf tapeworm
Taenia saginata	Taeniasis	Beef tapeworm
T. solium	Taeniasis	Pork tapeworm
Trichuris trichiura	Trichuriasis	Whipworm

Adapted from Feachem et al. 1983 as cited in Metcalf and Eddy 1991: 94; Kowal et al. 1981: 274, 318-319; Melnick et al. 1978; Holmes 1979 and Ffrench 1973: 63.

[a] Helminths listed are those with a worldwide distribution

[b] Source: Robins-Browne 1995

[c] Rao & Melnick 1986: 15

TABLE 4.1 Infectious agents potentially present in raw domestic wastewater

4.3.2.1.1 Bacteria

Bacteria are microscopic organisms that range in size from 0.2 to 10 μm in length. They are widely distributed in nature and have a considerable variety of nutritional requirements. Enteric bacteria normally reside in the intestinal tract of humans and animals. They assist in breaking down organic wastes produced by animals into products that can be utilised as a food source by plants. They are either aerobic (free oxygen requiring) or anaerobic (requiring an absence of free oxygen). Bacteria that can exist in both aerobic and anaerobic conditions are called facultative bacteria. *Escherichia coli* is an example. Enteric bacteria are primarily gram negative (thin fatty wall), nonspore forming rod shaped organisms. The two major enteric bacteria families are *Enterobacteriaceae* and *Pseudomonadaceae*. The *Enterobacteriaceae* family includes the following families and genera (Holt 1977):

1. *Escherichieae - Escherichia, Edwardsiella, Citrobacter, Salmonella;*
2. *Klebsielleae - Klebsiella, Enterobacter, Hafnia, Serratia;*
3. *Proteae - Proteus;*
4. *Yersinieae - Yersinia;* and
5. *Erwinieae - Erwinia.*

The 'total coliform' group and the 'faecal coliform' group, which have historically been used as indicators of faecal contamination in the environment, are from the *Enterobacteriaceae* family (Kowal et al. 1981: 276; Yates 1994: 143).

Enteric bacteria are not all pathogenic although given the right conditions some non-pathogenic bacteria may become virulent. In addition, all the bacterial pathogens have asymptomatic infections, human carrier states and non-human reservoirs, for example, domestic and wild animals, and poultry (Kowal et al. 1981: 276). Those most susceptible to disease will be the immunologically compromised and the debilitated.

Human faeces contains between 25 to 33% by weight of bacteria, mostly dead. Two sources, Carnow et al. (1979) and Feachem et al. (1978) attempted to quantify the numbers of viable bacteria per gram of wet faeces. The range of anaerobes varied from 10^3-10^{10}/g. These bacteria tend to die off quite rapidly when exposed to oxygen after being defecated from the body of an animal. For the aerobes, numbers range from less than 10^3-10^9/g, with enterobacteria varying from 10^6-10^9/g. These primarily include *Escherichia coli, Klebsiella* and *Enterobacter; Faecal streptococci* (10^5-10^8/g); *Staphylococcus*

($<10^3/g$); *Bacillus, Proteus, Pseudomonas* and *Spirochetes* ($<<10^3/g$).[4] The most significant levels of bacteria found in raw sewage as cited by Carnow et al. (1979) are as follows:

Enterobacteria (aerobic)	10^5/mL
Faecal *Streptococcus* (aerobic)	10^3–10^4/mL
Clostridium (anaerobic)	10^2–10^3/mL
Total bacteria content	10^6–10^8/mL

The presence and levels of pathogens in raw wastewater depends on the levels of infection in the contributing population. In an infected person, the levels of pathogenic bacteria can be quite high with figures ranging from 10^5–10^8/g, with most averaging around 10^6/g (wet weight) of faeces depending on the species (Feachem et al. 1978).

The various types of pathogenic bacteria found in wastewater are described as follows:

Campylobacter jejuni was isolated in 4–8% of patients in 1979 causing acute gastroenteritis and diarrhoea. It was thought to be as prevalent as *Salmonella* and *Shigella* (MMWR 1979). There are several different types of pathogenic strains of *E. coli* that produce acute diarrhoea by different mechanisms as listed in Table 4.1 (Robins-Browne 1995). They have a worldwide distribution. EHEC can cause more serious conditions of haemorrhagic colitis and haemolytic uraemic syndrome by being able to secrete large quantities of cytotoxins. About 60–70% of diarrhoea amongst travellers to developing countries is caused by the enterotoxigenic strain. *Leptospira* spp. are a group of spirochaetal organisms that are a borderline between bacteria and protozoa (Ffrench 1973: 62). Leptospores that infect humans normally inhabit an animal reservoir and require water as the medium for infection. They are excreted via the urine of animals, particularly rats that inhabit domestic sewers. Infection usually occurs from contact with infected urine. Fatality via Weil's disease, is low but increases with age, especially in those who develop jaundice and kidney damage. They are an occupational health hazard for rice field workers, farmers, sewer workers and miners. *Salmonella paratyphi* also has a low fatality rate usually producing mild attacks of gastroenteritis (Benenson 1975). *Salmonella typhi* has a fatality rate of 10% untreated and 2–3% treated with supportive measures. It occurs worldwide but is more common in developing countries (Benenson 1975). Other *Salmonella* spp., spanning over 1 000 serotypes, cause acute gastroenteritis that includes abdominal pain, vomiting, diarrhoea and fever. Death is uncommon except in the very young and

[4] Feachem et al. (1978) tended to quote figures and order of magnitude higher than Carnow et al. (1979).

the very old or debilitated. In 1979, 30 476 cases were reported in the USA (MMWR 1980). The *Shigella* spp. primarily cause acute enteritis in the colon, producing diarrhoea, vomiting, cramps and fever. Mortality rates are low. In 1979, 15 265 cases were reported in the USA (MMWR 1980). Death is uncommon from *Yersinia* spp.

The cholera bacterium, *Vibrio cholerae*, is spread by contaminated food and water. It produces a toxin in the gut that causes damage to the lining resulting in copious diarrhoea and dehydration that can be fatal. *Vibrio cholerae* has a fatality rate of 50% if untreated and less than 1% when treated. It has appeared again in Latin America in 1991 having spread throughout Asia and Africa in preceding decades, where it is again endemic (McMichael 1992: 280).

4.3.2.1.2 Viruses

Viruses are obligate intracellular pathogens in all other life forms. They can only replicate within a host cell. Structurally, they are simply a protein coat surrounding a core of genetic material (DNA or RNA). Some have a protective lipid envelope. Despite their simplicity they are very host specific. They are very small ranging from 20-200 nm in length. Their structure can allow relatively long survival in the environment under favourable conditions and they can cause an enormous range of diseases (Rose 1993: 1, 3; Yates 1994: 144).

Viruses enter the host mainly by the respiratory route or they can enter via the faecal-oral route. Viruses that infect the host by the gastrointestinal tract are called enteric viruses (Kowal et al. 1981: 295). The list of enteric viruses continues to grow and so far, over 120 types of viral agents have been isolated (Rose 1993: 1). The types of viruses commonly found in sewage are listed in Table 4.1. All of them are infectious to humans and may be regarded as pathogens since no virus is endemic to the intestinal tract (Rao & Melnick 1986: 1). Once they enter the alimentary tract they may multiply if stomach acids and enzymes do not inactivate them.

Most enteroviral infections cause few or no clinical symptoms. Although with continued multiplication in the lymphoid tissue of the pharynx and gut they may cause viremia whereby they enter the blood stream to infect target organs, such as; the liver (hepatitis), the central nervous system, the heart (myocardium), and the skin (Melnick et al. 1979; Evans 1976).

The most studied group of waterborne enteric viruses are the enterovirus group belonging to the picornaviridae family which includes poliovirus, coxsackie virus A and B groups, echovirus and the enterovirus types 68–72. As many as 10^{10} viral units/g of faeces can be shed by an infected individual. The well known poliovirus causes poliomyelitis, a disease consisting of fever and gastroenteritis that may progress to aseptic meningitis or flaccid paralysis. Polio poses a high risk to unimmunised populations with clinical disease occurring between 2–3 in 100 of those infected (Dr Richard Lord, 1996, pers. comm., 27 Aug.). Other enteroviruses can also cause paralytic disease, usually of a transient nature. In addition, mild respiratory disease may result from some enterovirus infections. Serious disease can occur in a small proportion of infections usually related to the health of the host (Rao & Melnick 1986: 10). Coxsackieviruses can cause a range of diseases including aseptic meningitis, herpangina, epidemic myalgia, myocarditis, pericarditis, pneumonia, rashes, common colds, congenital heart anomalies and hepatitis. Echoviruses can cause similar illnesses that also include encephalitis and paralysis. The new enteroviruses also can cause a wide range of diseases such as pneumonia, bronchiolitis, acute haemorrhagic conjunctivitis and hand-foot-and-mouth disease.

Hepatitis type A (HAV) is also an enterovirus (type 72) which has been clearly demonstrated to be responsible for waterborne epidemics as a result of sewage contamination. It is an RNA virus 27 nm in diameter. The largest recorded epidemic involve 30 000 cases in New Delhi in 1955-56. It can cause inflammation of the liver which is termed hepatitis. There are also a group of non-A, non-B hepatitis viruses that can be transmitted by wastewater. Fatality rates can be as high as 12% with pregnant women being the most susceptible (Rao & Melnick 1986: 11-12).

Rotavirus can cause acute gastroenteritis with severe diarrhoea and it is the major cause of non-bacterial diarrhoea in children (Flewett & Woode 1978) sometimes resulting in dehydration and death in infants. It usually strikes at wintertime in temperate climates (Konno et al. 1978). The virus is 70 nm in diameter and contains double-stranded RNA. Outbreaks have occurred in USA, the former USSR, Brazil and in Australia every winter (Rao & Melnick 1986: 13; Dr Richard Lord, 1996, pers. comm., 27 Aug.). Norwalk-like agents cause epidemic gastroenteritis with diarrhoea, vomiting, abdominal pain, headache and myalgia or malaise, although the illness is generally mild (Kapikian et al. 1979).

Adenoviruses are large double-stranded DNA viruses that cause respiratory and eye infections and are transmitted by the respiratory route particularly among bathers and are also believed to cause gastroenteritis in young children (Richmond et al. 1979; Rao & Melnick 1986: 13). Several types may lead to prolonged diarrhoea of more than 2 weeks (Rao & Melnick 1986: 14). Reovirus appears to cause minimal illness (Rosen 1979).

With the exception of rotaviruses, maximum recovery of other enteroviruses occurs during late summer and early autumn in temperate climates in raw wastewater (Rao & Melnick 1986: 25). Up to 6 850 viral units/L was reported in a one-year survey conducted on Australian raw sewage (Rao & Melnick 1986: 25–26).

4.3.2.1.3 Protozoa

Protozoa are single celled organisms that are usually larger than bacteria, ranging in size from 2 to about 200 μm (Roland & Cooper 1983: 30). A parasitic protozoan generally exists in two forms, the first is the cystic form, or resting stage, and it is this form that is present in sewage. The other form is called the trophozoite which is the active stage that multiplies in the intestinal tract of humans and animals. After a period of reproduction they 'round' up to form precysts which secrete tough membranes to become environmentally-resistant cysts or oocysts and are defecated in this form. They do not reproduce in the cystic form whilst in the environment but are capable of surviving in the environment for months (Yates 1994: 144; Ffrench 1973: 63; Brown 1969). The most common pathogenic protozoa found in wastewater are listed in Table 4.1.

Entamoeba histolytica is a free-living amoeba that invades the human lower small intestine, appendix, caecum, colon and occasionally other organs. It caused 58 deaths in Chicago in 1933 due to defective plumbing. The cystic form survives outside the human host up to ten days at room temperature and several weeks at cooler temperatures (Ffrench 1973: 63). It causes amebiasis with symptoms ranging from mild abdominal discomfort with diarrhoea to fulminating dysentery with fever, chills and bloody or mucoid diarrhoea. Most infections are asymptomatic although extreme cases of liver, lung or brain abscesses can result with possible death (Krogstad et al. 1978). Domestic and wild animals serve as reservoirs for *E. histolytica* (Kowal et al. 1981: 314).

Giardia lamblia is a flagellate, that is it has long thread like appendages used for swimming. Giardiasis, the disease caused by the parasite, often called 'traveller's disease', an often asymptomatic infection of the small intestine, which may develop into chronic diarrhoea, malabsorption of fats, abdominal cramps, bloating, fatigue, and weight loss. The carrier rate in the USA has ranged between 1.5-20% in different areas (Lin 1985; Benenson 1975). Beavers, dogs, sheep and possums serve as a non-human reservoirs for *Giardia* (Kowal et al. 1981: 314) and can therefore pass on infection to humans. It has a trophozoite (active) stage, whereby its body is flat, pear shaped and bilaterally symmetrical. It attaches itself within the host's intestine by aid of a suction disc. It reproduces by binary fission and then forms into cysts which are defecated in the faeces. The cysts contains two trophozoites and upon ingestion by a new host they open (excystation) to release the trophozoites which continue the cycle of infection (Rose 1993: 3).

At this stage, there appears to be no national prevalence data of *Giardia,* although it is the most commonly reported intestinal parasite in Australia. It is particularly prevalent where there is inadequate hygiene, poor nutrition and close community association with dogs that act as carriers (Meloni et al. 1993: 157; Boreham 1981). A survey of Aboriginal communities in the Kimberley region, WA, demonstrated *Giardia* as the most common intestinal parasite, with 32.1% and 12.5% of children and adults, respectively, being infected (Meloni et al. 1993: 157).

Balantidium coli is a ciliate that causes balantidiasis, a disease of the colon, characterised by diarrhoea or dysentery. Infections are usually asymptomatic and the disease incidence in humans is very low (Benenson 1975; Kowal et al. 1981: 314). Cysts found in wastewater mainly come from swine.

Cryptosporidium parvum is a coccidian parasite found in animal waste which causes a form of diarrhoea. It has a large zoonotic potential reservoir. More than forty host animal species have been identified (Casemore 1991 160). Like *Giardia,* it produces an environmental stage, called, 'oocysts' which are discharged into the environment in the faeces of infected individuals and sometimes find their way into drinking supplies causing recent epidemics in the United Kingdom and the USA. These oocysts can remain viable for up to 18 months. The oocysts are small (4-6 μm), highly infectious and contain four sporozoites which initiate the next intracellular infection (Bongard et al. 1994: 563). It has a complex life cycle undergoing both asexual and sexual

reproduction within the cells of the epithelium of the small intestine. It is now ubiquitous in distribution appearing in summer in Australia although reported cases are generally higher amongst children in Third World countries (Casemore 1991: 159). It is emerging as one of the most ignored causes of severe gastroenteritis. The organism has been found in 14 to 57% of samples of surface water taken from different locations in Western USA and it was implicated in an outbreak in Georgia, USA, affecting 13 000 people (Wiesner 1992: 242). The reported incidence of disease in Australia in 1993 was 52.4 people in 100 000 (Water and Wastes in NZ 1994). There is no known cure for the disease. The oocysts attach themselves to the wall of the gut where it reproduces, causing stomach pain and diarrhoea lasting 5 to 10 days with large fluid loss. Morbidity rates are between 60–80% (Rose 1993: 4). The disease can be quite protracted amongst the more susceptible members of the community, young children and immunocompromised people, for example, AIDS or leukemia sufferers (Wiesner 1992: 242).

An outbreak of 479 cases in greater Adelaide occurred in the summer of 1990/1991. Consumption of spring or mains water was implicated as the source of infection (Weinstein et al. 1993: 117). Adelaide relies on the lower reaches of the Murray that passes through 1 500 km of farmland for its drinking water thus making this organism a potential hazard.

4.3.2.1.4 Helminths

Helminths are strikingly different from the other infectious agents, since they are multicellular animals (parasitic worms) that, with rare exceptions, do not replicate within the host. On average, less than 10% of infections develop into overt disease (Warren 1993: 461). Pathogenic helminths of concern in wastewaters are listed in Table 4.1. They are divided into nematodes (roundworms), cestodes (flatworms or tapeworms) and trematodes (flukes). Trematodes require aquatic conditions and intermediary hosts and therefore can be present in aquaculture reuse systems. Protozoa and helminths are often grouped together under the term, 'parasites' (Kowal et al. 1981: 273).

The pinworm, *Enterobius vermicularis*, produces itching and discomfort in the perianal area, particularly at night. A 1972 estimate gave 42 million pinworm infections in the USA (Warren 1974). For Australia, numbers of people infected may range from 10 000–100 000 (Grove 1993: 464). The large roundworm, *Ascaris lumbricoides*, produces

eggs that hatch in the intestine and travel via the circulatory system to the pharynx. This causes coughing, chest pain, shortness of breath, fever and eosinophilia. These small worms then migrate back to the small intestine, and if they reproduce in large numbers, can cause further illness. Death occurs infrequently. The prevalence of ascariasis in the USA in 1972 was 4 million cases (Warren 1974). *Trichuris trichiura*, the human whipworm, lives in the large intestine. Light infections are often asymptomatic but heavy infections may cause intermittent abdominal pain, bloody stools, diarrhoea, anemia, loss of weight and possible rectal prolapse. The prevalence of trichuriasis in the USA in 1972 was estimated at 2.2 million (Warren 1974). The human hook worms, *Necator americanus* and *Ancylostoma duodunale*, live in the small intestine. Eggs are passed in the faeces and develop to an infective stage in warm moist soil. The larvae penetrate the skin, usually the foot, and migrate via the pharynx to the small intestine. Pneumonitis similar to ascariasis may occur (Benenson 1975). Heavy infections may result in iron-deficiency anaemia due to bleeding at the site of attachment, creating debility especially among children and pregnant women. Cases of hookworm infection were 700 000 in the USA in 1972 (Warren 1974). *Strongyloides stercoralis*, the threadworm, inhabits the upper small intestine. The larvae deposited in the soil also infects humans by penetrating the skin; they complete their lifecycle similarly to the hookworms. Intestinal symptoms include abdominal pain, nausea, weight loss, vomiting, diarrhoea, weakness and constipation (Benenson 1975). Cases of strongyloidiasis in the USA were 400 000 in 1972 (Warren 1974). *Taenia saginata* and *T. solium* are the beef and pork tapeworm that live in the intestinal tract where they may cause anorexia, loss of weight, abdominal pain, and digestive disturbances. The infection arises from eating improperly cooked beef or pork. The hazard is principally due to grazing cattle or pigs on land treatment sites and can be controlled by sufficient withholding periods. Cases of tapeworm are rare in the USA and Australia (Kowal 1981: 323).

Fortunately, Australia does not have many of the parasitic worms prevalent in the rest of the world. Worms endemic in Australia are: roundworm, whipworm, hookworm, threadworm, dwarf tapeworm, beef tapeworm, pig tapeworm, hydatid tapeworm, *Toxocara canis* and *T. cati* (NHMRC et al. 1996: 6). Most intestinal nematodes occur in the tropical north. Hydatid disease and tapeworm infections occur mainly in sheep and cattle farming areas. It is not known how many people in Australia are infected with helminths. Of particular concern to reuse schemes, the beef tape worm, *T.*

saginata, occurs in the south-east of the country, although infections are rare and can be controlled by properly cooking meat (Grove 1991: 464, 466).

Feachem et al. (1983) groups infections caused by sewage borne pathogens into five environmental categories (Appendix 10) that list the basic epidemiological features of these pathogens. Category I infections are those which are from pathogens that are infective once defecated and require low dose numbers to cause an infection, but cannot multiply in the environment. These would be called highly infectious organisms. This category includes enteric viruses, protozoa and certain helminths (parasitic worms). Transmission of these pathogens occurs mostly through person to person contact, although their survival in the environment does not preclude environmental infection.

Category II infections are caused by bacteria which are infective immediately after excretion but require large numbers to be ingested to be capable of causing disease. They can also multiply outside their host given the right circumstances. Their ability to survive in the environment means they can be transmitted to other hosts via reuse schemes apart from direct person to person transmission.

Category III diseases are the soil transmitted intestinal nematodes, such as the human roundworm, the hookworms and the human whipworm, which require no intermediate host. Their eggs require a latency period of development in the environment before they become infective. They only require one egg for infection and are resistant to the host's immunity. These nematodes are readily transmitted by agricultural use of raw or partially treated wastewater.

Category IV infections are caused by the beef tapeworm, *Taenia saginata,* and the pork tapeworm, *T. solium.* Their eggs must first pass through an intermediary host before humans can be infected by eating the undercooked meat of the infected animal. A potential route of infection is also via wastewater irrigation of pasture on which cattle or pigs graze.

Category V infections are caused by water-based helminths that require one or two intermediate aquatic hosts. The first host is a snail and the second is either a fish or plant. These type of helminths have a limited geographical distribution occurring particularly where aquaculture using poorly treated wastewater predominates.

The last three categories are all helminths that have a latency period. They can survive for long times in the environment varying from 2 weeks up to several years. Wastewater and sludge reuse schemes are important in regards to their transmission. The type of wastewater reuse scheme will largely regulate what sort of category infection will be favoured.

4.3.2.2 Pathogen Levels in Raw Wastewater

Raw wastewater consists of 99.9% water with the remainder containing dissolved or suspended chemical and biological solids (Conservation Council of Victoria 1993a: 2). Most municipal treatment plants do not receive sewage with high metal concentrations although some may have industrial inputs (Cort 1987: 38).

Pathogen Type	*Area*	*Concentration (per L)*	*Year measured*	*Source*
Salmonella	California	5 000–80 000		Stewart 1990
	Australia	40 000		McNeill 1985
Enteric Viruses	United States	0–7 000 units	1961–1978	Kowal et al. 1981: 299, 316 & 324
		5 650 pfu* (mean)	~ 1964–1976	Englebrecht 1976
		492 000 units		
		1 000–100 000 pfu		Melnick & Gerba 1980
				Arceivala 1981; Demichele 1974
	California	100–15 000 units		Yanko 1993
		105–106 units		Stewart 1990
	Melbourne	5 500 units (mean)		Smith 1982: 172
Protozoa				
E. histolytica	United States	4.0 cysts	1973	Kowal et al. 1981: 299,
		5 000 cysts	1956	316 & 324
G. lamblia	United States	9 600–240 000 cysts	1979	Kowal et al. 1981: 299,
		< 80 000 cysts	1978	316 & 324
	Florida	5.8 cyst		Rose 1993: 9
	California	9 000 - 200 000		Stewart 1990
Cryptosporidium	Florida	0.030 oocysts		Rose 1993: 9
Helminths		up to 10 000 eggs		Arceivala 1981
		66 ova		Foster & Engelbrecht 1973

* Plaque forming unit

TABLE 4.2 Typical levels of enteric pathogens in raw wastewaters

With regard to microbial hazards, the levels of pathogens in wastewater is highly variable, depending on the levels of infection in the contributing population, the size of the population, the socio-economic condition of the population and their eating habits (Kowal et al. 1981: 277, Rose 1993: 8; Shahalam & Mansour 1989: 149). This makes

estimating the levels of pathogens in raw sewage and their associated risks of infection also highly variable. Results of past studies are listed in Table 4.2.

The total bacterial content of raw wastewater, as recovered on standard media at 20°C, is about 10^8–10^9 organisms/100 mL (Carnow et al., 1979). Bacteria of faecal origin in raw municipal wastewaters average around 10^7 cfu/100 mL for enterobacteria[5], 10^5–10^6 cfu/mL for faecal streptococcus and 10^4–10^5 cfu/100 mL for *Clostridium*. The risk of infection from *Salmonella* spp. and *Shigella* spp. is potentially greater than from other bacterial pathogens because they tend to be the most common pathogens in wastewater (Kowal et al. 1981: 294).

The concentration of enteroviruses in the faeces of an uninfected individual is normally zero. In an infected individual, as many as 10^6 viral units/g of enteroviruses and 10^{10} vu/g of rotaviruses may be present in the faeces (Tyrrell & Kapikian 1982). Concentrations of viruses in wastewater will vary from area to area although it is thought to be lower in developed countries than in developing countries. Viruses are distributed worldwide and can spread without notice, or cause overt epidemics in late summer and early autumn in temperate climates (being around the time that most wastewater irrigation would take place). Children serve as the main vehicles for enterovirus spread since they have antigenic inexperience. Immunity is acquired with increasing age. The poorer the sanitary conditions the more rapidly immunity is developed although this will come at a cost. Conversely, in hygienic populations infection becomes more common amongst older people (Melnick et al. 1979; Benenson 1975). Vaccine poliovirus concentrations in sewage tend to remain constant throughout the year. Reported viral concentrations in sewage may only represent 1/10 to 1/100 of the actual concentrations due to the poor viral recovery techniques that were available in the past, although viral isolation techniques are improving.

With regard to protozoa, several studies give typical figures of the number of cysts an infected individual can excrete per gram of faeces. For *E. histolytica* an infected individual may excrete 1.5×10^5 cysts/g (Feachem et al. 1978). The concentration of *G. lamblia* cysts in the faeces has also been estimated at 10^5 cysts/g, up to 2.2×10^6 cysts/g in children and up to 9.6×10^7 cysts/g in asymptomatic adult carriers (Akin et al. 1978). As a comparison, Table 4.3 list levels of these pathogens found in the environment.

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[5] cfu = colony forming unit.

	Protozoan (oo)cysts/100 L	*Comment*
Canals	9.5	for Cryptosporidium
	< 1	for Giardia
Rivers	4–10	for Cryptosporidium
	< 1	for Giardia

TABLE 4.3 Levels of protozoa found in environmental waters

The levels of helminths eggs in sewage will depend on the number of infected individuals and the number of animals contributing to the system. For an infected individual, Feachem et al. (1978) suggests the number of eggs per gram of faeces are as follows: *Ascaris,* 10 000; *Taenia,* 10 000; *Trichuris,* 1 000 and *Necator and Ancylostoma,* 800.

4.3.2.3 Methods of Pathogen Detection and Indicators of Pathogens

Wastewater quality guidelines and standards for wastewater reuse are invariably expressed in terms of the maximum allowable concentration of an indicator bacteria in STP effluent that in some way represents the pathogens of concern. The indicator used is typically the faecal coliform bacteria group, of which the species, *Escherichia coli.* may be used. Faecal coliforms are used as indicators of faecal pollution because they only come from the gastrointestinal tract of warm blooded animals. The 'total coliform' group is also sometimes used, although this is less specific as an indicator since not all coliforms are exclusively faecal in origin.

In practice, faecal coliforms (FC) can be used as reasonably reliable indicators for bacterial pathogens since they have a similar morphology and similar survival rates during wastewater treatment and in the environment.

It has also been argued that the use of bacteria as indicators for viruses is a conservative option, and thus an attractive one, because viruses are not normal inhabitants of the gastrointestinal tract whilst bacteria are. Nevertheless, this has been shown not to be the case in some instances. Marzouk et al. (1979) isolated enteroviruses from 20% of Israeli groundwater samples, 12 of which had no detectable faecal bacteria. They concluded that no significant correlations between the two existed.

In addition, increasing evidence during the past 15 to 20 years suggests that the coliform group may not be an adequate indicator for all the non bacterial groups, that

is; viruses, protozoa and helminths due to behavioural differences between the organisms (Yates 1994: 151; Martin 1996: 26; Ashbolt 1995: 32). As a result, there has been considerable disagreement over how to measure microbial water pollution. The debate continues as to what indicators should be used for water quality (Millus 1993: 3) and, therefore, what should be the benchmark for water quality standards and guidelines (Allison et al. 1988: 1211). For instance, attention has been given to using bacteriophages[6] or enteroviruses themselves as indicators for viruses (Kowal et al. 1981: 298). A Colorado Springs study in 1984 set about to identify an adequate indicator as a basis for health standards (Section 4.3.4.2). This and other studies have failed to identify any other indicator apart from faecal bacteria that adequately represents all groups of pathogens whilst remaining cost effective (WHO 1989: 36).

Dufour (1984: 49) evaluated the characteristics of an ideal indicator for recreational water and found that the faecal bacterium, Enterococcus, could meet more of the required characteristics than could faecal coliforms or *E. coli* in fresh and marine water. *E. coli* did, however, exhibit a moderate correlation in fresh water only. Larkin et al. (1978a) found that total coliforms and faecal streptococci bore no relationship to the presence of *Salmonella* on crops and recommended using faecal coliforms or *Salmonella* itself to indicate contamination.

To overcome the dilemma of inadequate indicators for particular pathogens of concern, the USEPA (1989) in 1985 sought to bypass the problem by stipulating treatment requirements that were known to produce predictable reductions in viruses and protozoa, thus obviating the need for extensive pathogen monitoring.

Nevertheless, there has been a need to detect viruses in the environment because very small numbers of pathogens may be sufficient to cause an infection and thus present a public health risk. The direct detection of viruses and parasites requires large samples, usually ranging from one hundred to a thousand litres, since the concentration of these microorganisms is expected to be very low in treated sewage effluent (Rao & Melnick 1986: 4). This method of detection has been hindered by prohibitive costs, the need for skilled personnel, prolonged delays in test results and inaccuracies in the detection methods (Millis 1993: 3). Alternative surrogates have been sought, several of which

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[6] Bacteriophages or coliphages are viruses that live within bacteria and are specific to individual bacterial species.

have been identified as more or less suitable depending on the situation. Faecal coliforms, faecal streptococci and coliphages are among the options. Coliphages, such as, f2 and MS2 may have limited applications although some studies have yielded conflicting results on the comparative survival of coliphages and enteric viruses (Rao & Melnick 1986: 31-32).

In wastewater reuse applications it is necessary to detect pathogens in aerosols emanating from spray irrigation schemes. Due to the nature of aerosolisation and the small numbers of pathogens usually in aerosols, high volume samplers are often necessary for aerosol analysis (Kowal et al. 1981: 285). Indicators, such as, standard plate count, total and faecal coliforms are used because pathogens tend to appear in very small concentrations. Unfortunately, studies by Johnston et al. (1980) and Teltsch et al. (1980) show little correlation between levels of pathogens and levels of indicator bacteria in aerosols. They also found that the pathogens they studied survived better than the indicator organisms used thus giving underestimates of actual pathogen levels. They suggested that faecal streptococcus might be a more appropriate indicator organism because of its hardiness. Figures quoted below of aerosolised bacteria found at land treatment sites from around the world give some idea of typical concentrations. For raw or primary effluent, coliform densities varied from 11-496/m^3 (faecal coliforms 35-86/m^3) at a distance of 10 m from an irrigator, 0-88/m^3 at 100 m, 0-25/m^3 at 200 m and 0-4/m^3 at 400 m at an Israeli kibbutz (Katzenelson and Teltsch 1976: 710). For secondary unchlorinated effluent in California, faecal coliform and faecal streptococci were measured as 0.4/m^3 and 0.3-1.7/m^3 respectively at 30-50 m from the irrigators (Schaub et al. 1978; Johnson et al. 1978, 1980).

Johnson et al. (1980) also highlighted difficulties in using indicator organisms to monitor pathogens in aerosolised sprays. They concluded that for unchlorinated secondary effluent the traditional indicator organisms extremely underestimate the actual presence of pathogens in aerosol; that large volume samples (1 m^3/min) are necessary for obtaining useful aerosol data; and that heroic efforts are required to isolate enteroviruses in aerosols. Therefore, they recommended the use of predictive aerosol dispersion models as a more economic solution to risk assessment than extensive aerosol monitoring.

Nevertheless, new techniques are being constantly developed to isolate viruses. Electropositive or chemically-treated electronegative filters can adsorb viruses present

in environmental samples. These viruses are then either concentrated into a smaller volume and removed with the use of proteinaceous liquid such as beef extract (Yates 1994: 152). This sample can then be analysed for the presence of viruses using a number of techniques. An established method involves inoculating live cells and waiting for evidence of the deterioration of the cells. Patches of deterioration are called 'plaques' and hence the term plaque-forming-units (pfu). Unfortunately, this is a time consuming process which may take weeks to complete. These techniques are quite inefficient, with less than 20% virus recovery (Rao & Melnick 1986: 8). More rapid techniques have been developed, including radioimmunoassay (RIA) and enzyme-linked immunosorbent assay (ELISA). These require a specific antibody that acts against the virus of interest, unfortunately very high numbers of viruses are required (10 000 to 100 000). Recent advances in DNA technology are providing tools, such as, nucleic acid probes that can detect one virus and even a specific group of viruses. These also have limitations in that they cannot differentiate between infective and non-infective particles. The latest technology that has improved even further the sensitivity of virus detection is the polymerase chain reaction (PCR) technology. PCR enables the production of multiple copies of the genetic material of virus particles and thereby amplifying the ability to detect them. PCR equipment at present is only available for research purposes and many improvements have to be made before it is generally available for viral detection in the field (Yates 1994: 152; Cahill 1993: 233).

With the availability of these new techniques, Ashbolt (1995: 35) concludes that it may be more prudent to monitor a wider array of microbial groups directly, depending on the nature of the sample, with the inclusion of enteric viruses and parasitic cysts as indicators since they are probably closely related to the presence of agents of infection.

4.3.2.4 Pathogen Reduction in Sewage Plant Treatment

The levels of pathogens in effluent discharged from a sewage treatment plant depend upon the plant's treatment train. Individual unit processes can be placed in series to provide various levels of treatment: primary, secondary and tertiary (or advanced) treatment (Metcalf & Eddy 1991: 126; Harivandi 1994: 125). Depending on the type of treatment train, 50-99.99% of pathogens can be removed (Yates 1994: 146). These treatment processes can also be conducted in a number of different ways: conventional, lagoon or overland flow treatment (Conservation Council of Victoria 1993a: 4). Examples of these types of systems are schematically represented in Figure 4.2.

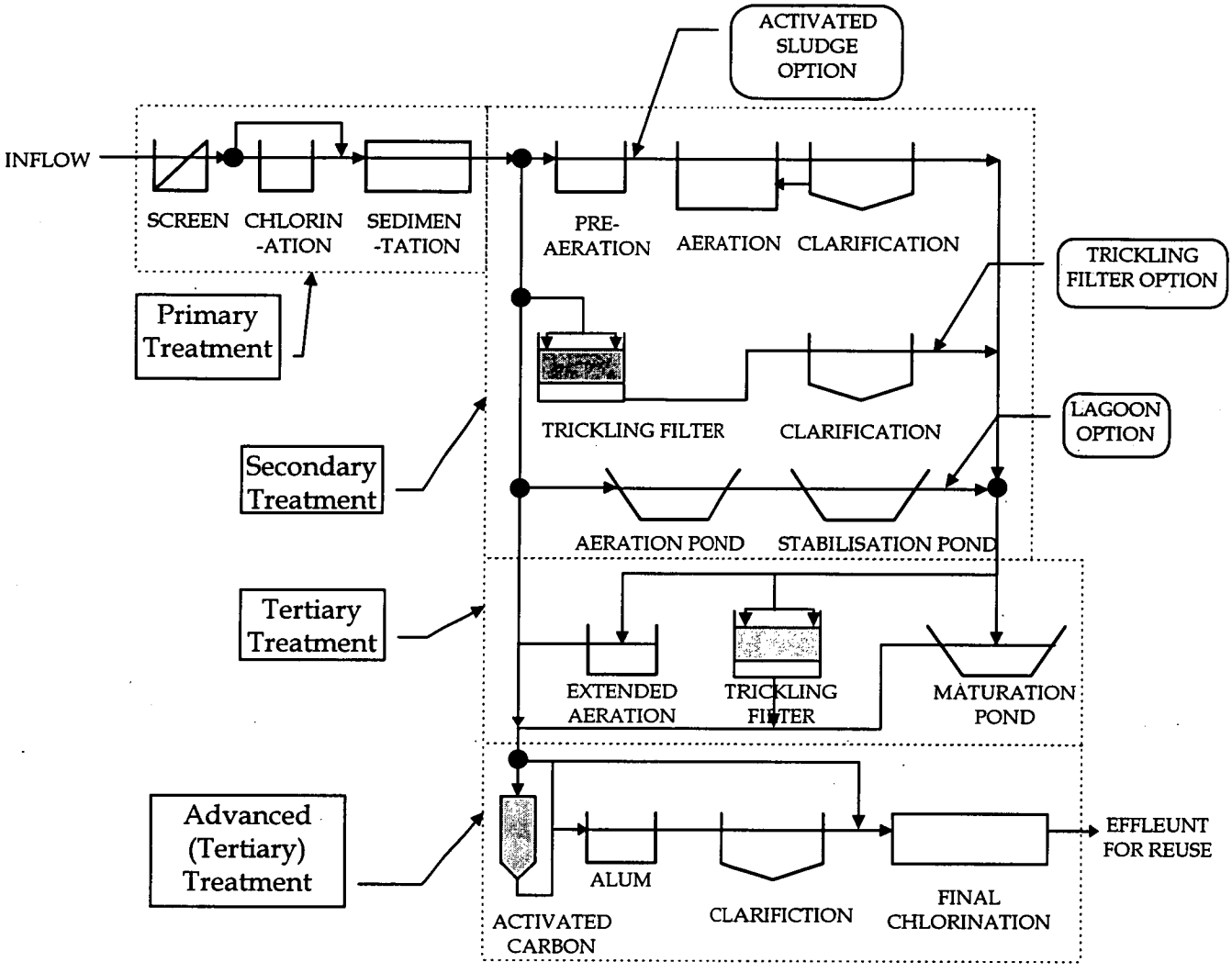

FIGURE 4.2 Typical wastewater treatment process
(Adapted from Shahalam & Mansour 1989:160)

Contaminants in wastewater can be removed by physical, chemical or biological means. Examples of physical operations are: screening, mixing, flocculation, sedimentation, flotation, filtration and gas transfer. Examples of chemical operations that involve either the addition of chemicals or other chemical reactions are: precipitation, adsorption and disinfection. Biological operations involve living organisms that decompose biodegradable organic material or remove nutrients, such as nitrogen and phosphorus. These organisms eventually settle out and are physically removed after they have metabolised these substances (Metcalf & Eddy 1991: 126).

The treatment process essentially divides the sewage into three components: gases, sludge and effluent. The gases are typically, CO_2, SO_2, CH_4 and NH_3. These are the by products of bacterial decomposition. In conventional systems, the sludge is usually

taken to an anaerobic (oxygen free) digester where naturally occurring bacteria decompose most of the organics. Methane (CH_4) produced by the digestion process can be used as a fuel source to heat the sludge thus obtaining optimum temperature conditions for digestion. The resulting digested sludge is then dried and usually disposed of at a landfill tip. The reuse of sludge is often restricted by the high levels of toxic substances and pathogens concentrated in the sludge (Rao & Melnick 1986: 42; Lance & Gerba 1978). Less contaminated or pasteurised sludge can be reused as a soil conditioner or used in ceramic building materials as an innovative method of reuse. The effluent is either discharged to a waterway, to land or reused (Conservation Council of Victoria 1993a: 5).

The degree of removal of microorganisms in wastewater by a treatment process is most easily expressed in terms of $\log_{10}$ units, for example, a reduction of 3 $\log_{10}$ units = 99.9% reduction. This may be interpreted as a significant degree of removal but it must be borne in mind that it is the absolute level of pathogen concentration that is important in ascertaining health risks. For example, a superficially impressive 99% removal rate for wastewater containing 10^5 pathogenic bacteria/100 mL will still result in the effluent containing 10^3 pathogenic bacteria/100 mL. This level may still be of public concern depending on how the effluent is used (Kowal et al. 1981: 279). Typical removal rates for different groups of microorganisms for different treatment processes are shown in Table 4.4.

4.3.2.4.1 Conventional Treatment Systems

Conventional treatment systems are mechanically driven systems that may be either an *activated sludge* system or a *trickling (biological) filter* system. These are technology driven systems requiring greater energy inputs than other systems. This is compensated by less space required and therefore they are more suited to large urban areas.

Before primary treatment, the sewage is initially treated by removing coarse solids that may interfere with downstream processes. Gross litter screens may be used to intercept and remove large objects, such as rags or sticks, or these are shredded into more manageable sizes by using comminutors. Sand and small stones are then settled out by slowing down the stream flow in grit chambers (Metcalf & Eddy 1991: 128).

Primary treatment itself is a physical process involving the removal of undissolved solids, oils and greases from the wastewater. Large settling tanks called 'clarifiers' are used to skim the oils off the surface and the remaining undissolved suspended matter settles to the bottom of the tank that is then drawn off as raw sludge for digestion (Metcalf & Eddy 1991: 128).

Treatment process	*Removal (log_{10} units) of pathogens*			
	Bacteria	*Helminths*	*Viruses*	*Cysts*
Primary sedimentation				
Plain	0-1	0-2	0-1	0-1
Chemically assisted[b]	1-2	1-3 h	0-1	0-1
Activated sludge[c]	0-2	0-2	0-1	0-1
Biofiltration[d]	0-2	0-2	0-1	0-1
Aerated lagoon[d]	1-2	1-3 h	1-2	0-1
Oxidation ditch[c]	1-2	0-2	1-2	0-1
Disinfection[e]	2-6 h	0-1	0-4	0-3
Waste stabilisation ponds[f]	1-6 h	1-3 h	1-4	1-4
Effluent storage reservoirs[g]	1-6 h	1-3 h	1-4	1-4
Secondary treatment	1.9-4.4 k	nd	0.3-3	0.3-1.5 l
Tertiary [j]	3.8-10 k	nd	3-8.7	1.8-6.3 l

Source: Mara, D. and Cairncross, S. 1989.
[b] Further research is needed to confirm performance.
[c] Including secondary sedimentation.
[d] Including settling pond.
[e] Chlorination or ozonation.
[f] Performance depends on number of ponds in series and other environmental factors.
[g] Performance depends on retention time, which varies with demand.
[h] With good design and proper operation the recommended (WHO) guidelines are achievable.
[j] Tertiary treatment here means secondary treatment plus disinfection, coagulation, filtration and disinfection, Source: Stewart 1990.
[k] Data for *Salmonella* only.
[l] Data for *Giardia* only.

TABLE 4.4 Expected removal of defecated microorganisms in various wastewater systems

Because viruses tend to be particle associated, primary settling of solids will account for their significant removal from the wastewater. Research indicates an average removal of 50% of viruses takes place in primary settling. Other research has indicated lower rates of removal ranging between 10-90% with 10% or less being more typical (Sproul 1978; Crites & Uiga 1979; Melnick et al. 1978). Primary sedimentation results in poor removal of protozoa such as *E. histolytica*. Different authors have reported removal rates from 0-50% (Cram 1943; Foster & Engelbrecht 1973; Sproul 1978; Crites and Uiga 1979).

The effluent from the primary treatment operation will still contain organic material with high levels of biological oxygen demand (BOD) not suitable for discharge into aquatic ecosystems, therefore necessitating further treatment. Secondary treatment is a

chemical or biological process that further reduces organics, suspended solids, pathogens, dissolved chemicals and solids by aerobic (oxygen rich) bacteria digestion. This stage involves either the use of a trickling filter or an activated sludge tank. The trickling filter unit is a bed of stones or plastic media that allows bacteria, algae and protozoa to grow as a 'mat like' film on their surfaces. Effluent is fed from the top and the microbial mats feed on the organic material in the effluent. The cleaner effluent passes out the bottom and into another clarifier that collects these biological mats as they grow and break off. Some metals, surfactants and organic halogens like chlorinated hydrocarbons may be reduced to some extent via this process. In the activated sludge unit, sewage after it leaves the primary sedimentation tank enters an aerated chamber in which bacteria break down organic matter and a new mass of bacterial cells are produced. From this the sewage is passed to another sedimentation tank where the biological mass settles down as sludge. Some of this 'activated' sludge, now saturated with bacteria and protozoa, is fed back into the aerated chamber for feeding, and hence activating, the decomposition of the incoming sewage (Rao & Melnick 1986: 43).

The activated sludge process is becoming a more popular form of secondary treatment. It requires less space, is free of flies and odours and tends to be more efficient in nutrient removal than trickling filters although operating costs are higher. Increasingly stringent requirements for effluent quality have resulted in a swing away from biological filtration to activated sludge systems. In addition, there have been two new developments in the last decade: the rotating biological contactor and the fluidised bed biological reactor (GHD 1983: 41).

Studies conducted on trickling filter units indicated virus removal between 40–77% depending on the hydraulic load on the plant and also poor removals of protozoa (Cram 1943; Foster & Engelbrecht 1973; Sproul 1978; Crites and Uiga 1979). Activated sludge units, however, display much higher removal rates of viruses. Rates of 90–99% of enterovirus removal were demonstrated in a plant in Bombay treating 19 ML/d and Irving and Smith obtained average removals of 93% for enteroviruses, 85% adenoviruses and 28% reoviruses in a Melbourne plant over a one year period (Rao & Melnick 1986: 43–44). Uiga and Crites (1980: 2866) reported other studies indicating removal rates of virus between 76–99% and removal as approximately 10%. Removal in this process is facilitated by viral adsorption onto solids which end up as components of the sludge.

Conventional secondary treatment combines the two processes of primary sedimentation and activated sludge or trickling filter units, which is then usually followed by disinfection (Metcalf & Eddy 1991: 128). In summary, the process of conventional treatment is to transfer the microbiota from the wastewater into the secondary biomass and the primary digested sludge (Sagik et al. 1979: 251).

'Tertiary' or 'advanced' treatment are terms that have many definitions that refer to effluent treatment beyond secondary level. It is a polishing process designed to specifically remove a particular pollutant. Most tertiary treatment systems are nutrient removal systems that seek to reduce nitrogen and phosphorous to counter nutrient overloading of aquatic ecosystems. Alternatively, it may involve the removal of specific toxic compounds, organic matter, suspended solids or ion removal depending upon the nature of the effluent and the discharge requirements. In addition, tertiary treatment may involve more stringent disinfection.

These systems may include a number of unit processes such as: coagulation, flocculation, sedimentation, filtration and activated carbon treatment (Metcalf & Eddy 1991: 128-9). Coagulation and flocculation consist of adding a floc-forming coagulant, such as: alum, $Al_2(SO_4)_3$; lime, $Ca(OH)_2$; or ferric chloride, ($FeCl_3$) to wastewater that combines colloidal solids that are slow or difficult to settle to produce a rapid settling floc that then can be removed by sedimentation. When the coagulant is added to water or wastewater it dissociates and the metallic ion forms a hydroxo-metallic ion that attracts negatively charged particles, including microorganisms. This process apart from chemical disinfection is very effective in removing viruses. One researcher discovered 25 mg/L of alum removed up to 99% coxsackievirus A2 (Rao & Melnick 1986: 47).

Filtration usually follows coagulation, flocculation and sedimentation in order to produce high quality effluent depending on the type of filter used. There are three main types:

1. *Single medium filters* that have only one type of media, usually sand, crushed anthracite or coal.
2. *Dual medium filters* that have two types of media: crushed anthracite and sand.

3. *Multimedia filters* that have three types of media: crushed anthracite, sand and garnet.

The effectiveness of these filters is associated with both the biological mat that forms on the surface of the media because they graze on pathogens in the effluent and the mechanical sieving of particles larger than the pore size of the media (Rao & Melnick 1985: 48).

It is important to note that even this form of treatment does not necessarily remove all pathogens (Yates 1994: 146). Available data suggests bacteria and virus removal is only nominal whereas it can be quite effective in removing helminth eggs (WHO 1989: 47).

A typical schematic diagram of a tertiary treatment process used in California is illustrated in Figure 4.3 (Asano et al. 1992: 1515):

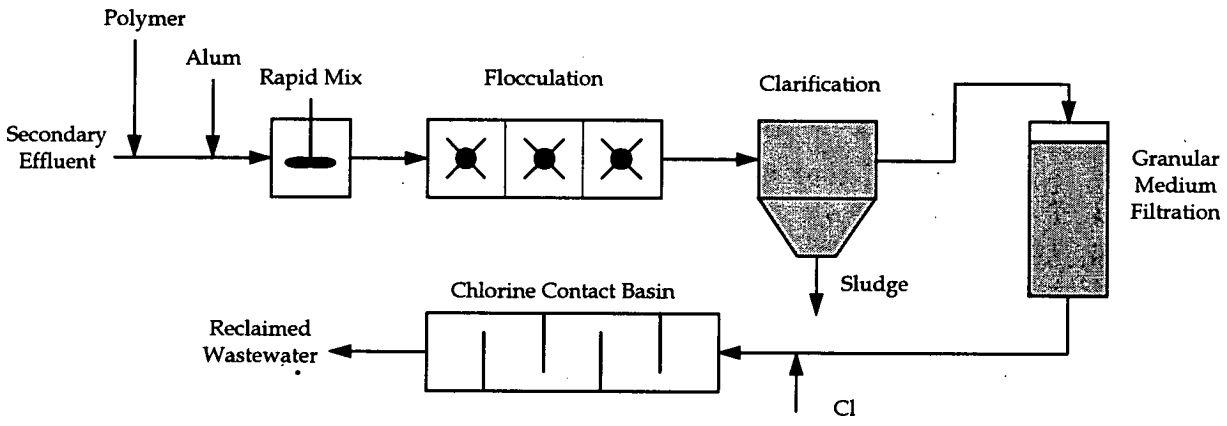

FIGURE 4.3 Advanced tertiary treatment process used in California

The first step of the process is the coagulation of suspended matter after addition of polymers and alum aided by rapid mixing. Next flocculation, being a slow stirring process, enables the complete coagulation of suspended matter. Clarification then allows the coagulated suspended matter to settle out of the waste stream. A granular medium filter removes the smaller particles and chlorination is added to kill any remaining microbes. This process is a very stringent 'full treatment' form of tertiary treatment and thus costly to operate. Costs involved in this treatment can be minimised by eliminating the flocculation process and/or the clarification process without significant loss of effluent quality, particularly when the quality of the secondary effluent is high. The lack of positive samples for virus in tertiary effluent indicates that it is essentially virus free 99% of the time, although due to daily and

seasonal variations, effluent quality is expected to vary (Asano 1992: 1523). Around Australia secondary treatment plants are being encouraged by environmental pressures to upgrade to tertiary treatment in order to remove plant nutrients (GHD 1983: 3).

Helminths eggs are heavier than water and thus settle out fairly efficiently with ordinary sedimentation, or conventional primary treatment. German engineers found that 1 to 2 hours of sedimentation detention time was sufficient to remove most helminth eggs (Sepp 1971). Conventional secondary treatment results in poor removal (Sproul 1978).

Oswald (1989: 67) noted that there is a greater risk of disease transmission with treatment systems that have short detention times and relying completely on chemical disinfection. This risk can be reduced by use of advanced integrated ponding followed by long-term storage for reuse applications.

4.3.2.4.2 *Lagoon Treatment Systems*

The second type of treatment system is the 'lagoon system' or 'wastewater stabilisation ponds' which essentially involve a series of shallow lakes inhabited by different varieties of bacteria which decompose the organic waste. It is a simple system involving low energy inputs, although its main drawbacks are the long detention time required, up to 40–60 days, for adequate natural disinfection and the large areas of land needed for the ponds. There are three types of ponds in common use (Feachem et al. 1978):

1. anaerobic pretreatment ponds, 2–4 m deep, 1–5 day retention time;
2. facultative ponds, with oxygen supplied by algae, 1–1.5 m deep, 10–40 day retention time; and
3. maturation ponds, 1–1.5 m deep, 5–10 day retention time.

Bacterial and viral numbers may be expected to decrease by 1–3 orders of magnitude in waste stabilisation ponds, depending on dilution, climatic factors and the hydraulic retention time, that is, the mean length of time that the water remains in the pond. Helminth eggs and amoebic cysts will settle to the bottom of the pond where they can remain viable for long periods of time (WHO 1989: 27).

Studies conducted at the University of NSW showed bacterial dieoff rate is sensitive to liquid depth and related factors of turbidity and algal concentrations, both of which affect light penetration. UV irradiation from the sun was found to be the main disinfecting factor. Increasing temperature and pH above 8 also increased dieoff rates (Barnes 1989: 603). In practice, intestinal organisms suffer first order decay during the passage through facultative and aerobic lagoons due to UV irradiation from the sun and from predation. Viruses, cysts and helminths are removed by adhesion and sedimentation.

These ponds are used extensively in NSW and to some extent in QLD where an average detention time is 20–30 days. The maximum depth of water is limited to 1.5 m ensuring effective solar irradiation disinfection. A disadvantage with the ponds is the lack of control over the disinfection process (McFaul & Jenner 1993: 225).

Feachem et al. (1978) after reviewing available literature found *E. coli* removals in a single anaerobic pond to range from 46–85% after 3–5 days at various temperatures. For both a facultative and an aerobic pond, *E. coli* removals up to 80 to more than 90% after 10–37 days at various temperatures have also been reported. Complete elimination of pathogenic bacteria can be achieved with 30–40 day retention times particularly at temperatures greater than 25°C. Aerated lagoons have been reported to remove 99% of faecal coliforms and *Salmonella typhi* (Crites & Uiga 1979). Times are not reported although aeration will accelerate the process of dieoff. Other data indicate utilisation of lagoons with extended aeration times is capable of rendering effluent almost pathogen free (Shahalam & Mansour 1989: 148).

Available data suggest a 50 day retention with multiple ponds in series accomplishes significant virus removals. Comparing seasonal variation in rates of disinfection, a secondary effluent pond in Israel in summer (18–20°C) achieved 100% removal with a 35 day retention whereas this result took 73 days in winter at 8°C (Feachem et al. 1978; Kott et al. 1978).

Wastewater stabilisation ponds appear to provide much better removal efficiencies for protozoa than do conventional methods. One hundred percent removal efficiency of cysts was obtained by a series of three ponds with a 7-day retention time in India (Arceivala et al. 1970) and also of *Giardia* cysts by a storage lagoon in Texas (Weaver et

al. 1978). Concentration of cysts in the sludge is likely to occur rather than cyst destruction.

Wastewater stabilisation ponds have been shown to achieve excellent degrees of helminth removal. Several sources report a 100% removal rate for 3 ponds of 6-7 days total retention time (Kowal 1981: 326). The eggs will settle into the sludge which must be properly treated if it is to be used on land. A series of waste stabilisation ponds in warm climates with a total retention time of 8-10 days can be designed to remove helminths eggs to less than 1 per litre but double this detention period would be needed to achieve less than 1 000 FC/100 mL (WHO 1989: 45).

Shahalam (1989: 39) in a review provided the following pathogen removal rates for stabilisation ponds (detention periods are not specified):

Faecal coliforms	99.6% (2 ponds at 18-25°C)
	99.9999% (3 ponds)
Viruses	50-80%
Helminth ova	100% (3 ponds)
S. typhi	99.5% (2 ponds)

Therefore, wastewater ponds can be designed to remove bacteria to any degree as deemed necessary for protection of public health. They appear to be more suited to tropical and sunny areas where land is readily available, nevertheless they can incur problems with excessive algal growth. Another disadvantages is the increase of TDS[7] due to evaporation. Barton and Arlosoroff (1987) listed some worldwide performance statistics of waste stabilisation ponds reproduced in Table 4.5.

Location	*No. of ponds in series*	*Retention time (days)*	*Effluent Quality (FC/100 mL)*
Australia (Melbourne)	8-11	30-70	100
Brazil (Campina Grande)[a]	4	23	450
France (Cogolin)	3	30	100
Jordan (Amman)	10	38	30
Peru (Lima)	5	38	100

Source: Bartone & Arlosoroff 1987: 298-297.

[a] Experimental Centre for Biological Treatment of Wastewater (Extrabes).

TABLE 4.5 Effluent quality of various stabilisation ponds

[7] TDS = total dissolved solids.

4.3.2.4.3 *Overland Flow Treatment Systems*

The third type of sewage treatment system is 'overland flow' or 'land and grass filtration' whereby wastewater is passed over land which then either evaporates, runs off as surface water or infiltrates the ground. It is a cheap and simple system that requires large areas of land similar to stabilisation ponds. Naturally occurring bacteria on the grass or in the soil break down the wastes. This system is similar to a wastewater reuse scheme although the philosophy behind it is disposal, not recycling or resource conservation. In addition, the application rates tend to be a lot higher for land and grass filtration than for reuse and the public is restricted from access. The wastewater is purified of pathogens by filtration and adsorption to the soil, desiccation, radiation and predation by soil microorganisms. Slow rate infiltration systems can remove 4-5 logs units of faecal coliforms (Crites 1984: 143A).

4.3.2.5 Pathogen Disinfection

Generally, disinfection of STP effluent is the last step in a treatment process. Disinfection is specifically designed to reduce numbers of defecated pathogens to acceptable levels before being discharged into the environment. Disinfection can be achieved in a number of ways: chemical oxidation, pH variation, UV irradiation, membrane technology, polishing lagoons, gamma radiation and heat. Chemical oxidation and use of lagoons are the most popular in Australia although some plants are implementing UV treatment or membrane technology.

Disinfectants need to be added to the effluent for the less time consuming and mechanically driven processes. Conventional treatment processes without disinfection will not produce effluent below 1 000 FC/100 mL nor will they be generally effective in removing helminth eggs. The less the wastewater has been treated the more disinfectant is usually required. These plants tend to be more temperamental than stabilisation ponds, even under skilled operation, requiring careful monitoring of the effluent. The constituents of effluent can very considerably from one sewage treatment plant to another even within the same state or country (Harivandi 1994, 107). In most cases sewage needs to be treated to a disinfected secondary or an advanced treatment level before it is suitable for greenspace irrigation. Sagik et al. (1979: 245) believe that low levels of potential human pathogens can be achieved with adequate secondary treatment followed by disinfection.

With regard to chemical disinfection, there are a number of chemicals which can be used: chlorine, chlorine dioxide, ozone, iodine, bromine and bromine chloride. Chlorine has been the most popular chemical oxidant, used since the early 1900s, because it is effective at relatively low concentrations, is relatively cheap and leaves a residue if added in sufficient doses (Rao & Melnick 1985: 50). Chlorination can provide an additional 90 to greater than 99% removal of certain pathogens (Sagik et al. 1979: 243). Chlorine gas reacts with water to form hypochlorous acid and hydrochoric acid. Depending on the pH, hypochlorous acid may then dissociate to form hypochlorite ion. These two species are termed 'free available chlorine' and are the disinfecting agents. Undissociated hypochlorous acid is the stronger disinfecting species of the two. Optimum pH for disinfection is about 6 (Rao & Melnick 1985: 50; GHD 1983: 43).

Chlorine disinfection efficiency is dependent on the initial chlorine dosage as well as the temperature, pH, presence of organic and inorganic nitrogenous compounds and the type of pathogens (WHO 1989: 46). Because of the presence of organic matter in effluent, large reductions of pathogens are difficult to obtain with chlorine disinfection. In addition, viral inactivation greatly varies among species and strains. Disinfection is more effective with lower turbidity in the effluent, typically ≤2 NTU[8] (Wilkins & Anderson 1991: 32, Crook & Okun 1987: 240). A free chlorine residual of 0.3–0.7 mg/L after a 30 minute contact time will generally result in a faecal coliform count of less than 10 cfu/100 mL. The dose required to achieve this will range from 2–8 mg/L for activated sludge effluents and up to 15 mg/L for trickling filter effluents. For a 99% inactivation of echovirus in secondary treated effluent, 8 mg/L of chlorine and a contact time of 1 h was needed and for poliovirus 20 mg/L was required over the same period (Rao & Melnick 1985: 51). Sorber et al. (1974) found that a standard-rate trickling filter plant with a chlorine residual of about 1.5 mg/L in the effluent gave a 3.7 log reduction of faecal coliforms (2.1 log reduction due to chlorine alone) and only a 0.4 log reduction for enteric viruses (0.3 log reduction due to chlorine alone) whereas a high-rate trickling filter plant with about a 4 mg/L chlorine residual in the effluent gave a 5.8 log reduction in faecal coliforms (3.6 reduction due to chlorine alone). In another study it took a chlorine dose 10 times that for coliforms to achieve an equivalent 99.9% inactivation for poliovirus (Smith 1982: 173).

[8] NTU = Nephelometric Turbidity Units and are a measure of turbidity.

Therefore chlorine is a very inefficient activator of viruses: they demonstrate themselves to be more resistant to chlorination than coliform bacteria. They also demonstrate higher survival capabilities than bacteria under various conditions (Rao & Melnick 1986: 4). Chlorine levels may be as high as 8 mg/L and still have little effect in secondary effluent (Berg 1973). Another problem with chlorine is its by-products which are known to be toxic and carcinogenic at high levels (Pinhoslter 1995: 177A, GHD 1983: 45). Where the formation of toxic by-products associated with the use of chlorine is of concern other options are normally sought.

Protozoans, such as *E. histolytica* and *Giardia,* are also very chlorine resistant (Hoff 1979). *Cryptosporidium* oocysts are resistant to a variety of disinfectants, particularly chlorine, therefore necessitating mechanical methods of removal such as filtration (Berkleman 1994: 274). The chlorine CT [9] needed to kill *Cryptosporidium* oocysts is 9 600, 640 times that required for *Giardia* cysts (Current & Garcia 1991). Protozoa are sensitive to freezing, heating above 65°C for 5-20 minutes and to drying. UV irradiation has some effect whereas ozone at 1-2 mg/L and chlorine dioxide have killed oocysts (Casemore 1991: 158). The importance of continuous and adequate filtration as a key to prevention of waterborne giardiasis has also been emphasised (Lancet 1980: 1176) since *Giardia* and *Cryptosporidium* cysts and oocysts can be found in secondary treated and chlorinated effluent (Gerba et al. 1996: 256).

Chlorine dioxide has been used as another option. It is a more powerful oxidant than chlorine gas and persists to maintain a longer lasting residual, although inactivation efficiency of viruses such as poliovirus 1 appears to be about the same (Rao & Melnick 1985: 53).

Ozone is a more powerful oxidant than hypochlorous acid and chlorine dioxide. In relatively clean water, ozone at a concentration of <1 mg/L achieves 99.9% inactivation of viruses in seconds. However in wastewater it reacts with organic compounds necessitating doses as high as 4-15 mg/L for 99.99% reduction in 1-5 min. Ozone is relatively unstable and must be used as soon as it is generated (Rao & Melnick 1985: 52). It is also more expensive to use and it reacts indiscriminately with organic

[9] CT is the product of the residual chlorine present in the contact chamber and the time of contact which represents the degree of efficiency of chlorine disinfection (Metcalf & Eddy 1991: 338).

compounds necessitating low concentrations of TDS for effective disinfection (GHD 1983: 45).

McFaul and Jenner (1993: 222) studied alternatives to chlorine by considering UV irradiation, chlorine dioxide, ozonation, membrane filtration and maturation (stabilisation) ponds. The first three options were found to be effective in the destruction of both bacteria and viruses although UV needs to have a clear quality effluent, that is, low turbidity, for maximum effectiveness. Ozone was found to have a high capital cost associated with it as compared to UV or chlorine dioxide. Chlorine dioxide is comparatively cheap to use although a less desirable option from an environmental point of view.

Membrane filtration is a means of physically filtering the effluent with pore sizes in the range of 0.1–10 μm, sufficient to remove bacteria but not necessarily viruses. Chemical attraction between the viruses and the membrane will improve capture but not probably not completely. There is also a high capital cost associated with this (McFaul & Jenner 1993: 225).

Rose and Gerba (1991b: 2093) found 14% of effluent samples taken from 24 STP in Arizona were positive for enterovirus (averaging 5 pfu/40 L for secondary treatment plants; 0.5 pfu/40 L for tertiary treatment plants using sand filtration and 2.0 pfu/40 L for stabilisation ponds with chlorination) and 41% of all wastewater samples contained *Giardia* cysts (averaging 48 cyst/40 L for secondary treatment; 0.32 cyst/L for tertiary treatment plants and 170 cyst/40 L for stabilisation ponds).

Table 4.6 reports pathogen levels in STP effluent for various forms of treatment plants around the world.

Place and treatment	*E. coli cfu/100 mL*	*Salmonella /L*	*Viruses pfu/L*	*Protozoa (oo)cysts /100 L*	*Comments*	*Source*
Melbourne SEPP activated sludge & waste stabilisation ponds	<2		1 959 (mean)			GHD 1983: 4; Smith 1982: 173
Activated sludge plant near Melbourne	840	very low	<27–1825			Smith 1982: 173
Brisbane's Luggage Point waste stabilisation ponds	-					GHD 1983: 4
For 3 Victorian Plants including lagoons	2–550 000				highest for lagoon plant	GHD 1983: 4
Canberra	3					GHD 1983: 4
Arizona - secondary treated and chlorinated				26	- for Giardia	Gerba et al. 1996: 256
				3.4	- for Cryptosporidium	
Arizona - tertiary treated with filtration				7.0	- for Giardia	
				3.0	- for Cryptosporidium	
California secondary treated and disinfected effluent		3–1 075			predicted	Stewart 1990
			2–200		67% of samples were positive	Asano et al. 1991
California tertiary treated		$4x10^{-6}$–7.0			predicted	Stewart 1990
USA - Secondary treated effluent and disinfected			2–7 150			Melnick & Gerba 1980
Florida - Activated sludge with disinfection - 2 plants			10–130		40–100% of sample were positive	Farrah, nd
Florida- activated sludge plus filtration & disinfection - 5 plants			0.03–0.5		0–17% positive	Farrah, nd
Florida - secondary treated				2.3–6.6	- for Cryptosporidium	Rose 1993: 9
				1.0–41	- for Giardia	
Florida - filtered secondary effluents				< 1	- for Cryptosporidium	Rose 1993: 9
				< 1	- for Giardia	

TABLE 4.6 Reported effluent microbial quality for several waste treatment plants

Foster and Engelbrecht (1973) attempted to relate treatment effectiveness to application of organisms per hectare per day for land disposal systems based on chlorinated effluent as reproduced in Table 4.7.

	Number of Organisms/ML				
Pathogen	Raw Wastewater	Primary Effluent	Secondary Effluent	Disinfection[a]	Organisms applied per ha per day[b]
Salmonella	5×10^9	2.6×10^9	1.3×10^8	1.3×10^5	9.8×10^3
Mycobacterium	5×10^7	2.6×10^7	4×10^6	4×10^3	3×10^2
E. histolytica	4×10^6	3.4×10^6	3.2×10^6	3.2×10^3	2.3×10^3
Helminth ova	6.6×10^7	6.6×10^6	1.3×10^6	1.3×10^3	9.8×10^1
Virus	1×10^9	5×10^9	5×10^8	5×10^5	4×10^4

[a] Conditions sufficient to yield a 99.9% kill
[b] applied at a rate of 5 cm per week

TABLE 4.7 Estimated wastewater pathogens applied to soil

In Australia, most of the smaller municipal treatment plants tend to treat wastewater to a secondary level followed by disinfection with chlorine gas, using trickling filters or activated sludge processes to provide an effluent quality of at least 20 mg/L BOD_5 and 30 mg/L of suspended solids (Leece 1992; GHD 1983: 3). Reuse schemes in Australia therefore tend to utilise this quality of effluent.

4.3.3 Exposure Assessment

The potential for human exposure in a wastewater reuse scenario can occur at a number of stages after the effluent has left the sewage treatment plant. These stages include the collection, transportation, storage, distribution and application of the effluent. From stage to stage there will be varying opportunities of exposure to microbiological hazards for particular groups of people. In addition, the severity of the hazard will also vary from stage to stage.

To calculate the degree of exposure to a particular hazard at each stage one must:

- identify the most highly exposed groups;
- identify the exposure pathways by which the pathogens may reach these exposed groups;
- quantify the frequency of exposure for each route of infection, that is, inhalation, ingestion or absorption through the skin or other orifices; and
- quantify the likely dose consumed during exposure for each route of infection (Maynard 1993).

People who are at most risk of being exposed to wastewater pathogens are those who either consume raw vegetables irrigated with effluent, consumers who eat insufficiently cooked pork or beef that comes from animals grazing on effluent irrigated fodder, agricultural workers and their families, crop handlers, neighbours of the schemes where aerosols from spray irrigation are generated and those who recreate on greenspaces irrigated with effluent (Maynard 1993).

Factors which influence the probability of a pathogen infecting someone via a wastewater reuse scheme are many and this makes an accurate determination of risk a complicated process. These factors are:

- the latency of the pathogen in the infected individual;
- to what extent it multiplies (in and outside its host);
- how well it survives the wastewater treatment process;
- its persistence and natural decay in the environment;
- whether or not it requires an intermediary host;
- the type of reuse scheme practiced;
- the type of human exposure;
- how the person behaves during exposure and the person's immunity;

- the minimal infective dose required for infection;
- the distance of the irrigated fields from population centres; and
- the irrigation method and timing and hydrological factors affecting flow to aquifers (Avnimelech 1993: 1280; Shuval et al. 1986).

4.3.3.1 Exposure Pathways

There are several possible routes of exposure to pathogens in reclaimed water. Examples of pathways for infection are:

- aerosols, where the effluent may be aerosolised by spray irrigation or high winds;
- water bodies, that people may have contact with or swim in;
- vegetative matter that is irrigated with effluent which people may touch or eat; and
- groundwater contamination where effluent percolates into underground drinking water supplies and wells.

Indirect or secondary infection by coming into contact with an individual who has already been exposed to pathogens in effluent can also occur. This exposure pathway must not be underestimated as it has been significant (Yates 1994: 153).

Table 4.8 lists potentially exposed groups and the expected mode of intake in effluent reuse scenarios.

Wastewater can be applied to land by various methods and these influence the possible ways that pathogens can be transmitted (WHO 1989: 51), these are:

1. Border irrigation - whereby the crop is enclosed by a ridge and the land surface within is flooded;
2. Furrow irrigation - whereby parallel lines of furrows and ridges are made. The plants inhabit the ridges and are irrigated by flooding the furrow;
3. Sprinkler irrigation - the soil and crops are wetted by a nozzle sprinkler expelling droplets of water into the air;
4. Subsurface irrigation - whereby the irrigant is applied under the soil surface; and
5. Localised irrigation - such as drip, trickle or bubbler irrigation where the water is applied to the root zone at a regulated rate.

Pathway	*Microbial Hazard*	*Exposed Groups*	*Mode of Intake and Maximum Exposure*
Potable Reuse	All pathogens	Households/public via drinking, showers and cooking.	Ingestion (2 L/day) Skin Eyes
Primary recreational contact	All pathogens	Public	Ingestion (100 mL/day) Skin Eyes
Crops (eaten raw)	Virus and helminths	Public food chain, farm families, home gardens	Ingestion (10 mL/day)
Crops (processed)	Nil	As above	
Soil Water	Virus and helminths	Public, Food chain, farm families	Animal Product, accidental soil ingestion (200 mg/day)
Irrigated grass or pasture	Virus and helminths	As above	Ingestion (1 mL) and Skin
Airborne aerosols	Virus and bacteria	Farm families and neighbours	Inhalation, ingestion, skin and eye
Airborne dust	Viruses and helminths	As above	Eye
Groundwater	Virus	Public and farm families	Ingestion (1 L/day)
Surface water	Virus	As above	

Source: Adapted from Maynard 1993

TABLE 4.8 High risk exposed groups according to pathogen pathway

Border irrigation probably exposes workers to the highest health risk whereas subsurface irrigation with the use of plastic cover sheeting provides the greatest protection for workers. Worker protection does come at a cost. Border irrigation is the cheapest form of irrigation and subsurface is the most expensive, requiring high capital cost for equipment and installation and requiring a higher quality effluent in order to prevent clogging of the emitters. Bubbler irrigation can provide a good compromise and is commonly used for tree plantations. Sprinkler irrigation under strong winds can easily carry wastewater that form into aerosols when leaving the irrigator nozzle thus placing neighbouring residences at risk.

Figures 4.3a and 4.3b are flow charts describing the pathways of exposure for a crop irrigation scenario and a restricted but publicly accessible greenspace irrigation. The first column of text boxes indicates the type of pathogen of concern and the arrows refer to the direction of pathogen travel. The second column refers to the environmental media where the pathogens enter and then infect those who have contact with the media. More than one step may be required before a pathogen

reaches a host. The two diagrams are very similar with the exception that domestic animals as well as wildlife can act as a vectors of transmission for crop irrigation whereas endemic wildlife may act as vectors of disease for greenspace irrigation.

Accidental cross connections can either refer to a potable pipeline being cross connected with recycled water pipelines or accidental use of the taps or ports of recycled water lines for potable purposes. Wastewater reuse guidelines (Section 4.4) usually specify preventative measures to minimise the risk of this happening. Helminths are treated separately since they are not carried by aerosols or airborne dust due to their relatively large mass and therefore have a tendency to drop to the ground fairly readily. Protozoan cysts also due to their mass will not be carried far in aerosols.

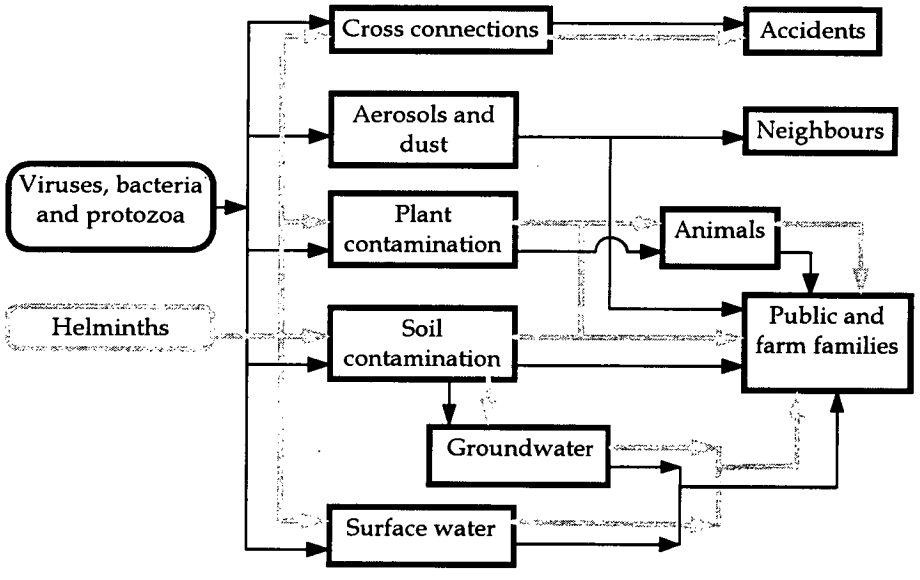

FIGURE 4.3a Exposure pathways for animal pasture, fodder, seed, fibre crops and treelots irrigated with wastewater
(Source: Adapted from Maynard 1993)

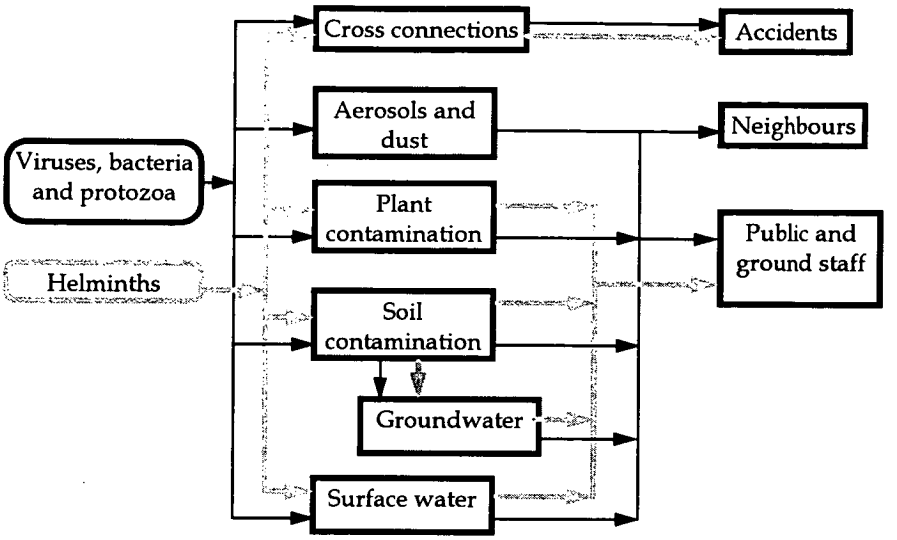

FIGURE 4.3b Exposure pathways for restricted landscape irrigation with wastewater. (Source: Adapted from Maynard 1993)

4.3.3.2 Pathogen survival in the environment

Pathogen survival in the environment after leaving the STP depends on a complex interplay of environmental factors (Shahalam & Mansour 1989: 149). Survival times for a particular microorganism depend on a wide range of climatic factors and the morphology of the organism. The climatic factors that influence survival are:

- temperature;
- humidity or wet conditions;
- sunlight;
- predators; and
- duration of exposure.

In terms of coliform bacteria, it is important to note that their survival time in the environment is dependent on their initial numbers.

4.3.3.2.1 Survival of Pathogens in Surface Waters

Bacteria

Pathogenic *E. coli* can survive in wastewater at 28°C for 12 days, *S. typhi,* up to 5 months at 20°C and *Vibrio cholera* up to 39 days (Shahalam 1989: 40).

Faecal coliforms can survive in fresh surface water 16 d at 4–6°C, 9 d at 9–14°C and <4–8 d at 18–25°C. *Salmonella* spp. survive in fresh water 16–49 d at 4–6°C, <4–35 d at 9–14°C and 2½–28 d at 18–25°C. Survival in marine water is significantly less for faecal coliforms (McNeill 1985: 63).

Viruses

Survival in fresh water for poliovirus ranges between 46 h-75 d at 3-8°C and 19 hr-20 d at 19-25°C. For Coxsackie and Echoviruses survival in fresh water varies slightly for each type although generally they survive between 58 h-90 d at 3-8°C and 7 hr-17 d at 19-25°C (McNeill 1985: 59).

In polluted water bodies, poliovirus can survive in wastewater up to 23 days at 20°C, Coxsackievirus up to 41 days at 20°C and Hepatitis A for over 10 weeks at 20-23°C (Shahalam 1989: 40). At 4-8°C enteroviral survival ranges between 10-231 d. Viruses tend to adsorb to particles. Samples taken from Galveston Bay, Texas had viruses detected in 72% of samples with suspended solids, 51% of sediment samples and only 14% of samples of clear water. Viruses adsorbed to sediments also remain infectious and survive longer in the marine environment. Sediments can be resuspended during storms or any other disturbance increasing the potential for infection, particularly of shellfish and swimmers (Rao & Melnick 1986: 7).

Protozoa and Helminths

Entamoeba cysts have been found to survive several months in water at 0°C, 3 days at 30°C, 30 min at 45°C, and 5 min at 50°C (Freeman 1979). *Giardia* cysts can survive up to 77 days in water at 8°C, 5-24 days at 21°C, and 4 days or less at 37°C (Bingham et al. 1979). *Nector americanas* has been known to survive in wastewater for up to 18 days at 15.5°C and *Taenia saginata* can survive more than 16 days at 18°C (Shahalam 1989: 40).

4.3.3.2.2 *Survival of Pathogens on Crops and Turfgrass*

The application of wastewater on food crops, especially those eaten raw, raises obvious public health concerns. Pathogen survival on plants tends to be less than that in the soil since they are exposed to sunlight and desiccation. Nevertheless, survival times can be long enough for them to reach the market and be consumed along with the fruit or vegetable. Different crops provide slightly different survival times depending on how much protection the crop can provide against the elements. In addition, no conclusive data existed in 1979 to suggest that non-traumatised edible plant tissue uptakes pathogens from contaminated soil except watermelon (Sagik et al. 1979: 250; Dr. Richard Lord 1996, pers. comm., 27 Aug.). The survival times of pathogens on soils and plants are of primary concern when deciding how long access or harvesting must be restricted for land irrigated with effluent. Cracks and splits in produce do provide

harbouring places, although pathogens do not penetrate into vegetables or fruits unless their skins are broken (WHO 1989: 28; Bryan 1977).

Mancino & Pepper (1994: 186) consider the likelihood of human disease occurring via secondary or tertiary treated effluent irrigation for turf is low.

Bacteria

Coliform bacteria have been recorded as surviving between 6–35 d on fodder, tomatoes and leaf vegetables (Uiga & Crites 1980: 2867). *E. coli* in particular has been noted to survive up to 8 d on grass. *Salmonella* spp. survive from 3–53 d on an assortment of vegetables and up to 42 d on grass. Notably *Salmonella* survives longer in the environment than *E. coli*. *Shigella* spp. have significantly lower survival times on vegetation ranging between <2–8 d. *Vibrio cholerae* likewise survives for several days on crops (Kowal et al. 1982: 289). Rudolf et al. (1951) cited a 7 day persistence of *Salmonella* and *Shigella* on tomatoes. These data support the need for at least a 15 day withholding period for aboveground produced exposed to bacteria.

Viruses

Intact surfaces of vegetables are probably impenetrable to enteroviruses. On the surface of aerial crops virus survival would be expected to be short due to exposure to the elements. It is noted to be similar to bacterial survival. Viruses do not multiply on foods or on other environmental media since for this they require living host cells.

Badaway et al. (1990: 937) undertook studies to determine the survival rates of enteric viruses and coliphages on grass irrigated with unchlorinated secondary treated effluent. Poliovirus type 1 and rotavirus type SA-11 had a 99.8% reduction after 10 h when the temperature increased from 22 to 41°C. There was a sharp increased in decay rate above 38°C.

During winter, when the temperatures varied between 4–16°C, coliphage MS-2 had a 99.99% reduction after 24 h and a 99.99999% (7 log unit) reduction after 40 hours. Poliovirus decreased by 96% and 99.6% after 24 and 40 h respectively. Rotavirus could not be detected after 40 h. Most of the disappearance occurred between daylight hours when temperature and light intensity were at a maximum. Nevertheless, this figures are quite deceptive. The grass was inoculated at 6 p.m. the night before with 10^6 pfu/g of poliovirus1. By 6 a.m. the following morning the percent reduction were only 95, 52,

86% for MS-2, Poliovirus 1 and Rotavirus SA-11 respectively. This equates to 4.8×10^5 pfu/g which is still a high infective concentration. Nevertheless, levels of virus will not usually be this high in treated sewage effluent. Badaway et al. (1990) concluded that wastewater irrigation may present a small risk especially on grass that children can roll in or even ingest. These authors also suggested that the allowable viral level in the effluent from Arizona STPs to be used on publicly accessible areas be the same as that used for food crops, that is, 1 pfu/40 L.

At a site in New Mexico where secondary effluent has been applied for 33 years by a ridge-and-furrow method, no enteroviruses were found on or in the leaf and grain portions of corn (Koerner and Haws 1979). Bagdasaryan (1964) reported survival of enteroviruses on tomatoes and radishes to be 2 weeks under household storage. After 10 d, numbers of enteroviruses on tomatoes were found by another study to reduce by 90% at 3-8°C and 99% at 18–21°C (McNeill 1985: 69).

The data hence supports the need also for a 15 day withholding period before harvesting produced exposed to viruses and washing them in clean water before sale. Survival times are listed in Table 4.9.

Protozoa and Helminths

On plant surfaces cysts do not survive for long due to their exposure to air. Rudolfs et al. (1951b) cited 3 days of dry weather survival for *E. histolytica* cysts on lettuce and tomatoes, and 35 days for immature *Ascaris* ova. Helminth eggs will dieoff more rapidly on plants that are exposed to sunlight and desiccation than in soils. Rudolfs et al. (1951c) also documented survival of helminth eggs up to 27-35 days on tomatoes and lettuce.

4.3.3.2.3 *Survival of Pathogens in Soils and Groundwater*

Factors affecting survival and viability[10] of pathogens in the soil are: moisture content, moisture holding capacity of the soil, temperature, pH, sunlight, organic matter and endemic soil microorganisms (Gerba et al. 1975). The survival of each pathogen will be considered for each environmental media or pathway.

[10] Viability of a pathogen refers to its ability to incite an infection in the human host.

The use of contaminated or inadequately treated groundwater has been the cause of approximately 50% of waterborne disease outbreaks in the USA since 1920 (Craun 1991). Any practice that involves domestic wastewater application to land has the potential to cause contamination of groundwater and hence underground potable water supplies.

Bacteria

Moisture and low temperature increase longevity of *E. coli, Salmonella typhi* and *Mycobacterium* in soils. Organic matter also enhances survival partly due to its moisture holding capacity. Conversely, survival time is shorter in sandy soils that have low moisture holding capacity and in acidic soils as opposed to neutral or alkaline soils. UV irradiation, competition, antagonism and predation from endemic soil microorganisms, particularly protozoa, will also reduce bacteria numbers (Gerba et al. 1975).

Specific examples indicating these relationships are cited by Sagik et al. (1979: 246). Early studies showed that *Salmonella typhi* could be recovered from loam and peat soils for periods of up to 85 days, whilst in drying sand their survival was only 4-7 days (temperature was not cited); they could survive as long as 2 years at freezing temperatures. Mycobacteria, due to their waxy consistency can survive dry conditions for longer periods of time.

Removal of bacteria from liquid percolating through soil is due to both mechanical removal (ie., straining or sieving at the soil surface) and adsorption to soil particulates. Studies conducted in Romania showed 92-97% of bacteria were retained in the first centimetre of soil, while 3-5% were detected at depths between 1-5 cm, although soil type was not indicated (Gerba et al. 1975). Decreasing pH and increasing cation concentration, which influences the cation exchange capacity (CEC), will enhance particle adsorption of microorganisms that are negatively charged. Turfsoil (predominantly sand) at high wastewater loading rates of up to 364 mm/week (Mancino & Pepper 1994: 187) removed *E. coli* with very high efficiencies (99% or greater). Under poor adsorption conditions, coliforms have been noted to move distances of 0.9-465 m in a variety of soils (Gerba et al. 1975). Goyal et al. (1980: 554) also raised the possibility of bacterial endotoxin contaminating the groundwater via land treatment. They found that 90-99% of endotoxin in wastewater was adsorbed

after travel through 100-250 cm of loamy sand soil and that it could then be remobilised by distilled water.

Survival of *E. coli* in sandy effluent irrigated soil was recorded as >25 d at 22-30°C and >8 d at 40-43°C in effluent irrigated alluvial desert (Ferguson & June 1952). In another study (Morris & Feeley 1976), the period for 99% reduction in faecal coliforms in organically rich coarse loam was found to be: 8-18 d in spring; 15-25 d in summer; 45-55 d in autumn; and 25-40 d in winter. In dense clay the results were: 15-25 d in spring; 10-15 d in summer; 15-25 d in autumn; and 25-40 d in winter. Survival of *S.typhi* was found to be 105-120 days at 4-15°C and 28-35 d at 12-26°C in clay.

Viruses

UV irradiation, moisture, temperature, pH and adsorption to soil particles (determined by the soil CEC) are factors that affect the survival and retention of viruses in soils. Soil microorganisms appear to have a less important effect on virus degradation than for bacteria (Kowal et al. 1981: 304; Sagik et al. 1979: 247). Desiccation and higher temperatures decrease longevity of viruses in soils (Sagik et al. 1978) and it appears that viruses will not survive for more than 100 days unless subjected to very cold conditions. Viral survival in soils is summarised in Table 4.9.

Yeager and O'Brien (1979), and Ward and Ashley (1977), studied the mechanism of virus inactivation in soils and found that irreversible damage occurred in poliovirus 1 when it released its RNA molecule from the within the outer shell (capsid) to be subsequently damaged under non-sterile soil conditions.

It is believed that most virus inactivation occurs in the top few centimetres of soil where drying and radiation forces are at a maximum although viruses have been found to penetrate down to 20 m in sandy soil (Wellings et al. 1978). Goyal et al. (1984: 299) isolated virus from groundwater beneath wastewater irrigated cropland. Gerba et al. (1977) demonstrated that high pH for extended periods is virucidal.

Virus adsorption increases with ion-exchange capacity (CEC), clay content, organic carbon content and glycerol-retention capacity (Sagik et al. 1979: 248). If de-ionised water is applied after viruses have adsorbed to soil particles, they desorb and move downwards in the soil column. Plants are unlikely reservoirs for viruses when used with soils because under natural conditions rapid adsorption of viruses by soil

particles prevents plants from absorbing them. Turfsoil (predominantly sand) at high wastewater loading rates of up to 364 mm/week (Mancino & Pepper 1994: 187) removed poliovirus type 1, echovirus type 5 and Coxsackie B3 virus with very high efficiencies (99% or greater).

Sagik et al. (1979: 247) also cite some figures of loss of viral titre as a function of temperature and soil moisture content. Effect of temperature on the survival of poliovirus in soils at 15% moisture content showed lower temperatures favour longer survival times. A 1 log unit reduction of viral titre required 3 months at 4°C, one month at 20°C and less than 1 week at 30°C. Soil moisture of 15–25% resulted in poliovirus 1 being detected beyond 4 months with an approximate 1 log unit (90%) reduction after 4 weeks whereas drying resulted in no detection of virus after 3 weeks (Duboise et al. 1976). Notably, Yeager and O'Brien (1979a: 698), discovered a threshold moisture level between 1.2–2.9% soil moisture (dry weight basis) below which viral inactivation increased dramatically. No viruses were viable in dry soil independent of temperature, soil type or water quality although drying times differed for various soil types. Therefore, by allowing the soil to dry and aerate between applications of wastewater will reduce or eliminate viral migration into groundwater systems.

In Australia, Smith (1982) had undertaken a comprehensive experimental program regarding the microbial hazards of irrigating vegetables with sewage effluent at Frankston, Victoria, studying the bacteriological, viral and heavy metal loading caused by effluent. Bacteriological testing showed that the levels were not significantly different from those on vegetables commonly available from the markets. The chlorinated reclaimed water was detained for some days before use. Viral levels were reduced to minimal proportions as a result of this detention. Most viable viruses were found to die off within 48 hours after applying the effluent to the vegetables (Smith 1982, GHD 1983: 21).

Protozoa and Helminths

Entamoeba cysts have been reported to only survive for 18–24 h in dry soils and 42–72 h in moist soil (Rudolfs et al. 1959). Beaver and Deshamps (1949) reported 8–10 day survival in damp loam and sand at 28–34°C.

Helminths in contrast to other pathogens can live for long periods in the soil. Under favourable conditions *Ascaris, Trichuris* and *Toxocara* can remain infective in soil for

several years (Little 1980). Hookworms can survive up to 20 weeks and *Taenia saginata* up to two years (Feachem et al. 1978).

Eggs of *T. saginata*, the beef tapeworm, can be viable up to six months in the soil under cool conditions, making the common practice of withholding cattle for only several weeks from effluent irrigated pasture questionable. With pig tapeworm, pigs only become infected if they have direct access to human faeces. The risk of transmitting the worm via effluent irrigation is quite low (WHO 1989: 28).

Feachem et al. (1978; 1983) and Bryan (1977) summarise the typical ranges of survival times in warm climates (20°C-30°C), shown in Table 4.9.

Pathogen	*Survival Time*	
	In soil	*On crops*
Bacteria		
Coliforms	4 to 77 days[a]	< 35 days[a]
Faecal coliforms	<70 but usually < 20 days	< 30 but usually < 15days
Faecal streptococci	8 to > 70 days[a]	-
Salmonella spp	<70 but usually < 20 days	< 30 but usually < 15days
Vibrio cholerae	<20 but usually < 10 days	< 5 but usually < 2days
Mycobacterium	10 to < 450 days[a]	10 to > 35 days[a]
Enteroviruses (polio-, echo- and cosackieviruses)	< 100 but usually < 20 days (70-170 days in sandy or loamy soils at 10-20% humidity, 3-10°C or 25-110 days at 18-23°C, Coxsackievirus 161 days in clay soil after 300 mm rainfall, at -12-26°C, polio- and coxsackie- 12 days in sandy loam, saturated at 37°C)	< 60 but usually < 15 days (Tomatoes 90% reduction of enterovirus after 10 days at 3-8°C, and 99% reduction after 10 days at 18-21°C)
Protozoa		
Entamoeba histolytica cysts	<20 but usually < 10 days	< 10 but usually < 2 days
Helminths		
Ascaris lumbricoides eggs	Many months < 90 but usually < 30 days	< 60 but usually < 30 days < 30 but usually < 10 days
Hookworm larvae	Many months	< 60 but usually < 30 days
Taenia saginata eggs	Many months	< 60 but usually < 30 days
Trichuris trichura eggs		

Sources: Feachem et al. (1983; 1978) and Bryan (1977)
[a] Temperature not specified for these.

TABLE 4.9 Survival times of selected defecated pathogens in soil and on crop surfaces at 20–30°C.

Note that the measured rates of dieoff depend upon the initial concentration of the microorganism and the sensitivity of detection methods.

4.3.3.2.4 *Survival of Pathogens in Aerosols*

Where wastewater is applied by some form of spray equipment, aerosols will be produced that will travel beyond the wetted area depending on prevailing wind conditions. Aerosols are suspensions of solid or liquid particles up to 50 μm in diameter. The numbers of microorganisms in aerosols will depend on their initial concentration in the effluent, the aerosolisation efficiency of the irrigator, the nozzle size, water pressure, angle of spray trajectory, angle of spray entry into the wind and impact devices on the irrigator (Schaub et al. 1978). For example, downward-directed, low-pressure sprinklers generate less aerosols than upward-directed and high-pressure types (Kowal et al. 1981: 286). Generally speaking, only 0.1–1.0% of the effluent is generated as aerosols when sprayed and wind can spread pathogens up to 750 m downwind (Avnimelech 1993: 1280). The rate of physical aerosol decay, wind speed and topography will all affect the distance aerosols can travel.

The major route of infection by pathogens in aerosols is inhalation. Aerosols above 2 μm in diameter will deposit in the upper respiratory tract, including the nose. From there they are carried by cilia to the gastrointestinal tract. The greatest deposition of aerosols occurs in the range of 1–2 μm and below 0.25 μm whereby they enter the small airways and are deposited in the alveoli of the lungs. No cilia are present in the alveoli requiring local mechanisms to deactivate pathogens (Sorber & Guter 1975).

Bacteria

Aerosolised bacteria suffer from 'aerosol shock' when emitted from the irrigator nozzle: this may reduce their numbers by 1 log unit within 10 seconds. Ongoing survival is then determined by air humidity, air temperature and UV irradiation. At low humidity, rapid desiccation occurs causing bacterial dieoff. Ultraviolet irradiation and high temperature also contribute to the dieoff of bacteria. Therefore, nightime irrigation in cold and humid conditions favours bacteria survival. Therefore the public must be restricted when irrigating during these conditions and appropriate barriers must be in place to avoid aerosol drift into neighbouring residences.

Teltsch and Katzenelson (1978) found aerosolised bacterial survival at night was up to ten times higher than that during the day in Israel. In other experiments in Israel, *E. coli* could only be detected in aerosols 10 m from the sprinkler when its concentration in effluent exceeded 10^6 cfu/100 mL. Teltsch et al. (1980: 1183) from the Kibbutz 'Tzora' took 25 samples over a 15 month period, finding levels of *Salmonella* varied

between 0-0.054/m^3, with a mean of 0.014 cfu/m^3, 40 m downwind, using raw wastewater that had an initial *Salmonella* concentration of 0-60 cfu/100 mL.

To estimate the actual exposure to bacterial pathogens in aerosols, using the above data from the Kibbutz 'Tzora', an adult male engaged in light work, breathing at a rate of 1.2 m^3/hr, would inhale *Salmonella* at a rate of 0.017 cfu/h at 40 m. This is still very low compared to the dose required for infection (Section 4.3.4.1). The risk of infection can be expressed as a hyperbolic relationship with increasing distance from the sprinkler (risk $\propto$ 1/distance).

Viruses

Viruses will also be contained in aerosols, thus being capable of being inhaled and transported to the gastrointestinal tract, or they may multiply in the respiratory tract itself. Aerosol shock may result in a 1/2 log unit removal of virus levels (Sorber 1976). The subsequent dieoff is estimated at one log unit every 40 sec and, as with bacteria, this is heavily influenced by solar radiation, temperature and relative humidity (Lance & Gerba 1978). Viruses with lipids survive better at lower humidities although most enteric viruses do not have lipids (Carnow et al. 1979). Under the least desirable conditions Sorber (1976) has estimated that three log unit viral reductions would occur over 200 m. Shuval (1978) detected enteroviruses in aerosolised wastewater 100 m downwind after the effluent received only 3-5 d detention time (10^6 pfu/100 mL). Teltsch et al. (1980: 1183) also found enteroviruses at up to 100 m downwind from the source of land treatment sites in Israel. Two studies (Johnson et al. 1980 & Teltsch et al. 1980), one in Israel and one in California, tried to quantify the presence of aerosolised viruses using high volume samplers. The Californian study used unchlorinated secondary effluent with a typical mean enterovirus density of 188 pfu/L. The sampler detected a mean density of 0.014 pfu/m^3 50 m downwind. The Israeli study had only one sample at 50 m downwind containing 0.14 pfu/m^3 although raw wastewater was used containing 650 pfu/L. Teltsch et al. (1980: 1186) also found that the ratio of enteroviruses to total coliforms increases with distance downwind from the sprinkler indicating that viruses are more persistent. Johnson et al. (1980) concluded that the likelihood of finding viruses in aerosolised secondary treated and unchlorinated wastewater as very small.

Based on the lower level of 0.014 pfu/m^3, a worker performing light work at 50 m, breathing at a rate of 1.2 m^3/h would inhale 0.13 pfu of enteroviruses in 8 hours. One

must remember that these figures are based on inefficient recovery rates so the actual inhalation rate could be as high as 13 pfu in an 8 hour day and technically only one virus needs to be able inhaled to cause an infection (Kowal et al. 1981: 302) thus presenting a real risk of infection. This would imply unchlorinated secondary treated wastewater is suitable for irrigation provided that public access to within a 50 m radius is restricted.

Protozoa and Helminths

Protozoa and helminths are unlikely to find their way into either aerosols or groundwater because of the large size of their cysts and eggs compared with bacteria and viruses (Kowal et al. 1981: 313).

In summary, the evidence suggests that pathogens of concern can survive in the environment to the extent that they can present a health hazard to those exposed through farming, eating or recreational activities related to wastewater reuse and that care must be exercised by ensuring a realistic multibarrier approach is adopted which minimises the potential risk of infection.

4.3.4 Dose Response Assessment

If a pathogen manages to survive all the treatment and environmental processes, as described previously, and reaches the human target, it still must overcome the body's various natural defenses before it can initiate an infection that leads to an illness. Firstly, pathogens encounter nonspecific immunologic responses and then further interactions result in specific immunological responses.

Common terms such as, 'infective dose' and 'minimum infectious dose' are non specific and misleading for there can be several types of responses by a person when inoculated. The term 'dose' refers to the number of organisms that enter the host. When a specified dose enters the human host, the result of the pathogen-host interaction may be either: no infection, an infection without illness or an infection with illness. The particular response is dependant on many factors listed below (Kowal et al. 1981: 291, Rose 1993: 3):

1. The host's defence mechanisms available to fight a pathogen depend on the site of pathogen entry. For example, direct inoculation into the bloodstream results in the fewest barriers to overcome;
2. Previous exposure to a given pathogen produces varying degrees of immunity to that pathogen. It is important to note that children are more susceptible to gastrointestinal disease. Young children after weaning are at the highest risk of infection because of lack of acquired immunity. In 1973, in the USA, infant mortality due to waterborne infection was 20 times higher than that for the general population (Greene 1982: 155). Gastrointestinal disease is also a major killer of young children in developing countries;
3. Age, general health and use of immunosuppressant drugs will affect susceptibility to infection;
4. Frequency of exposure to the pathogen;
5. The virulence or pathogenicity of a pathogen, for example virulence will vary between strains of bacteria and the observed frequencies of symptomatic infections to nonsymptomatic infections for various enteroviruses may range from 1% to more than 75%.

Consideration by risk managers of heterogeneity in a population needs to be taken into account in order to conduct a robust risk assessment. A subset of a population will be more or less at risk depending on their degree of exposure, their age and their immunity levels.

Infectious dose information is scarce since infectious dose studies depend upon the willingness of human volunteers to be inoculated. Nevertheless, dose-response data are available and have been collated from different sources (Table 4.10). Several things must be borne in mind when reviewing this data: firstly infectious doses vary depending on the health of the subject at the time of inoculation; secondly, the occurrence of infection is measured by a variety of different methods making comparisons difficult; and finally, infectivity of laboratory grown organisms used to inoculate subjects may not exactly replicate the infectivity of environmental pathogens (Gibbs & Ho 1993: 18).

4.3.4.1 Infectivity of pathogens

4.3.4.1.1 Infectious Dose of Bacteria

Many bacterial cells are required to initiate an infection and therefore they present a lower risk of infection than do other pathogens (Table 4.10). Notably, virulence varies among strains, for example, three strains of *Shigella flexneri* have infectious doses that range from 180–10^{10} organisms (NRC 1977).

4.3.4.1.2 Infectious Dose of Viruses

In contrast with bacteria, only a few virus particles, and indeed only one, are necessary to be able to produce an infection under favourable conditions (Rao & Melnick 1986: 4). Laboratory evidence both *in vitro* and *in vivo* provides strong evidence that one virus particle is capable of establishing an infection in cell culture and in a mammalian host. Therefore, the risk of viral infection will not be eliminated, even though extreme dilution of viruses in the environment will greatly reduce such a risk (Sagik et al. 1979: 251). Rose and Gerba (1991a: 31), recognising this, have listed the probabilities of infection resulting from ingesting one such virus or protozoan (Table 4.10). The results are highly variable, probably due to differences in experimental conditions, nevertheless they indicate that the infective dose is low, possibly in the order of 10 virus particles or less.

Pathogen	*No infection*	*Infection*	*Probability of Infection from 1 organism**	*Doses required for the following percentage of human volunteers to develop an illness*				
				1*	1–25	26–50	51–75	76–100
Bacteria								
Campylobacter			7×10^{-3}	1.4				
Clostridium perfringens	–	–			–	10^{8}–10^{9}	10^{9}–10^{10}	10^{9}
Escherichia coli (pathogenic strains)	10^{4}	10^{4}–10^{10}			10^{3}–10^{8}	10^{8}	10^{6}–10^{10}	10^{10}
Salmonella typhi	10^{3}	–	3.8×10^{-5}	263	10^{5}–10^{8}	10^{3}–10^{8}	10^{4}	10^{8}–10^{9}
Salmonella spp.	10^{4}–10^{9}	–	2.3×10^{-5}	4.3	10^{5}–10^{6}	10^{6}–10^{9}	10^{7}–10^{8}	10^{9}–10^{10}
Shigella dysenteriae	–	–	4.97×10^{-4} [c]	20	10^{1}–10^{2}	10^{2}–10^{3}	10^{3}–10^{4}	10^{4}–10^{5}
Shigella flexneri	–	–	1×10^{-4}	100	10^{2}–10^{4}	10^{3}–10^{4}	10^{4}–10^{5}	10^{5}–10^{8}
Shigella sonnei						10^{2}–10^{4}		–10^{4}
Streptococcus faecalis	10^{8}	–			10^{9}	10^{10}	–	–
Vibrio cholerae								
classical			7×10^{-6}	1428				
El Tor			1.5×10^{-5}	667				
$NaHCO_3$-buffered	10^{1}	10^{3}			–	10^{3}–10^{8}	10^{4}–10^{6}	–
unbuffered	10^{4}–10^{10}	–			10^{3}–10^{4}	10^{8}–10^{11}	–	–
Viruses[a]								
Adenovirus		0.5–9 HID_{50}						
Attenuated Poliovirus (vaccine)	0.2 pfu	2 pfu–$10^{7.6}$ $TCID_{50}$						
Poliovirus 1			1.49×10^{-2}	0.67				–$10^{7.5}$
Poliovirus 3			3.1×10^{-2}	0.32				
Coxsackie A		6–34 HID_{50}						
Coxsackie B								
Echovirus 12		10–100 pfu[c]	1.7×10^{-2}	0.59				100 pfu
Rotavirus			3.1×10^{-1}	0.03				–100
Norwalk Agent					1–10	10–100	10^{2}–10^{3}	10^{3}–10^{4}
Hepatitis A					1–10	10–100	10^{2}–10^{3}	10^{3}–10^{4}
Protozoa								
E. histolytica		1 cyst[b]	2.8×10^{-1}	0.04				<100
Entamoeba coli		1 cyst						
Giardia lamblia		1 cyst[b]	1.98×10^{-2}	0.5				<100
Cryptosporidium		1–100 oocysts						
Helminths								
Ascaris lumbricoides						1–10		10–100
Anclyostoma duodenale						1–10		10–100
Trichuris trichura						1–10		10–100

Sources: Adapted from Bryan 1977; National Research Council 1977; Rendtorff 1979; Beaver et al. 1956; Shahalam 1989: 39; * Source Rose & Gerba 1991a: 31; Ward and Akin 1984: 304, 307.

HID_{50} = dose required to infect 50% of volunteers inoculate.

[a] Oral dose figures are in terms of tissue culture dose 50% (TCD_{50}) or plaque-forming units as indicated.

[b] Theoretical value.

[c] End result was clinical illness.

TABLE 4.10 Infective doses of pathogens

Couch et al. (1965) and Gerone et al. (1966) reported that the human inhalation infective dose of Coxsackievirus A21 to be ≤ 18 TCD_{50}[11] which is comparable with the oral infectious dose (OID).

Using pigs to model dose response to enteroviruses in humans, the OID was found to be 1 800–2 500 pfu for porcine enterovirus Type 3 and 600–750 pfu for Type 7 but no perceptible illness occurred until dosages of 10^4 pfu were reached (Cliver 1980).

Rose (1993:3) reported from a summary of the *Morbidity and Mortality Weekly Report* that many states in the USA have reported a 10 fold increase in cases of aseptic meningitis due to echoviruses and coxsackie B viruses throughout 1991[12]. Therefore, due to the low infective doses required to cause an infection, extreme care should be taken to avoid human exposure to enteric viruses via aerosols or contact with crops or greenspaces irrigated with effluent.

4.3.4.1.3 Infectious Dose of Protozoa and Helminths

Protozoa require even fewer numbers to cause an infection than do viruses. Rendtorff (1954a & b) found that infections were produced by only ten cysts of *E. histolytica* and *Giardia*. Infections have been produced also by only one cyst of *E. histolytica* and the same is likely to be true for *Giardia*. However, the pathogenicity of protozoa are highly variable among strains and human responses are also variable: many are asymptomatic (Kowal et al. 1981: 317). Infectious dose is also thought to be small for *Cryptosporidium*: probably 1–100 oocysts (Casemore 1991: 158).

Only one viable helminth egg is required to cause an infection in humans. Nonetheless, the symptoms of infection are dose-related and many light infections are asymptomatic (Kowal et al. 1981: 327).

Data has been compiled by Gerba and Rose (1993) on the likelihood of an infection developing into a clinical illness or death once a person has become infected by various pathogens. This material is adapted in Table 4.11.

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[11] TCD_{50} or $TCID_{50}$ is the infectious dose that causes 50% of inoculated cultures to display a cytopathic effect (cpe).

[12] Rose quotes in the text the year 1991 but in her references uses the year 1990. Therefore it is unclear which year she is referring to.

Pathogen	*Frequency of clinical illness of people infected, %*	*Mortality rate in general population, %*	*Mortality rate in the elderly, %*
Bacteria			
Salmonella	41	0.1	3.8
Escherichia coli 0157:H7		0.2	11.8
Shigella	46	0.1	
Viruses			
Polio 1	0.1–1	0.90	
Coxsackie			
A2		0.50	
A4		0.50	
A9		0.26	
A16	50	0.59–0.94	
B2	11–50	0.59–0.94	
B3	29–96	0.59–0.94	
B4	30–70	0.59–0.94	
B5	5–40	0.59–0.94	
Echo			
overall	50		
6		0.29	
9	15-60	0.27	
1	rare-20		
20	33		
25	30		
30	50		
Hepatitis A			
adults	75	0.6	
Rotavirus			
adults	56-60	0.01	0.1
children	28	0.001	
Norwalk	40–59	0.0001	
Adenovirus		0.01	
Astro (adults)	12.5		
Protozoa			
Giardia	50–91		
children	61		
Cryptosporidium	71		

Source: Gerba & Rose 1993; Rose 1993: 2; Gerba et al. 1996: 255; Rose et al. 1991: 711.

Table 4.11 Ratio of clinical to subclinical infections and mortality rates of various pathogens

From the table, the data indicate the likelihood of incurring an illness after being infected varies greatly. An approximate average likelihood of developing an illness is in the order of 50%. Nearly all enteric pathogens can cause death although the rates for the general population are less than 1%. Nevertheless, higher risks of mortality occur amongst the very young, the aged and the immunocompromised. Immunity may not provide long-term protection against reinfection in the case of some pathogens. This is particularly so for Norwalk virus and *Giardia*. (Gerba et al. 1996: 255).

4.3.4.2 Epidemiology of Wastewater Reuse

With regard to waterborne disease generally, figures obtained for the United States between 1920 and 1990, affirm that a total of 1 674 outbreaks occurred involving over 450 000 people and resulting in 1 083 deaths (Craun 1991; Herwaldt et al. 1992). Despite an improved reporting system, the Centre for Disease Control in the USA estimates that actual yearly clinical waterborne infections are much higher due to only a fraction of them being reported. They estimated annual clinical cases to be around 940 000, involving 900 deaths (Bennett et al. 1987). The causes of these outbreaks have tended to be contamination of untreated, inadequate or interrupted disinfection of groundwater drinking supplies.

Giardia and *Cryptosporidium* have increased in their importance as waterborne pathogens. In particular, *Cryptosporidium* has a wide range of animal hosts. It has been implicated in at least five outbreaks in the USA, the largest affecting 400 000 people in 1993, and at least seven outbreaks in the UK (Newman 1995: 17A; Berkelman 1994: 273). High turbidity, heavy rains, winter snow melt and runoff from dairy farms, concentrating oocysts in the water supply, may have caused the large outbreak in the USA. An outbreak of *Cryptosporidium* in Sheffield, England resulting in 62 cases was attributed to water supplies being contaminated by cattle. An outbreak of giardiasis involving 363 cases was also reported in British Colombia as a result of beavers contaminating a chlorinated water reservoir (Hrudey et al. 1991).

The aetiological agents most responsible for known waterborne disease in the USA from 1971–1990 have been, *Giardia* (over 18% of all cases), *Cryptosporidium* (9.2%), Viral gastroenteritis (8.9%), Campylobacter (3.7%) and Salmonella (1.7%). In almost half of the cases, the causative pathogen was unknown (Craun 1991: 20; Herwaldt et al. 1992). It is suspected though, that most of the unknown pathogens are viruses, with Norwalk virus being suspected to have caused 23% of all the outbreaks (Keswick et al. 1985).

4.3.4.2.1 *Epidemiological Evidence for Disease Due to Wastewater Reuse*

Evidence supporting the spread of disease through wastewater irrigation is scarce. Bryan (1977), in a review of epidemics due to wastewater contaminated foods over a 70 year period, cited only 14 cases associated with wastewater irrigation of vegetables and, in all but two, untreated wastewater was utilised. Typhoid fever was the most common illness, followed by salmonellosis.

There were no confirmed reports up until 1987 of any disease outbreaks occurring in California as a result of irrigating with reclaimed sewage (Cort 1987: 38). No adverse health effects were reported from farm workers, consumers or wastewater treatment personnel after more than 16 years continuous land application of secondary effluents at Meza, Arizona (Stone & Rolands 1980). A study by Kleene et al. (1993) concluded that the risk of infection from public contact with lawn daily irrigated with treated domestic wastewater in summer appeared to be no greater than that associated with conventionally managed lawns. At the Werribee farm in Melbourne there has never been a reported epidemic or outbreak among employees and residents and their incidence of illness have been no different to that of the general community (Croxford 1978).

However, reports from Geldreich and Bordner (1971), Hoadley and Goyal (1976) and Sepp (1971) attest to the transmission of enteric diseases when using raw wastewater. Salmonellosis has been traced to the consumption of wastewater irrigated celery, watercress, watermelon, lettuce and cabbage; shigellosis to pastureland, and cholera to vegetables in Israel (Kowal et al. 1981: 295). Shuval (1993) linked an outbreak of typhoid fever and cholera transmission to raw wastewater irrigation in Santiago, Chile. Faecally-polluted vegetable gardens in Brazil have been found to contain polioviruses and coxsackieviruses which have been associated with earlier epidemics (Christovao et al. 1967a, b). A few epidemiological studies have linked the transmission of amoebiasis to vegetables irrigated with raw wastewater or fertilised with night soil (Bryan 1977; Geldreich and Bordner 1971).

Nevertheless, the causes of a large number of outbreaks cannot be identified because the illness is a nonspecific gastroenteritis or the disease goes unreported (Craun 1991: 20). The aetiology of many viral illnesses in particular remains hidden because the symptoms are common to many types of viruses. Hepatitis A virus is the only virus

that is easily identifiable from patient symptoms. Therefore, actual cases of epidemics due to effluent reuse may be higher than recognised at present.

After WHO (1989: 37) tabled their guidelines in 1973, major efforts were made by WHO, the World Bank, the United Nations Development Program, the UN Environment Program, the International Development Research Centre, Canada, the International Reference Centre for Waste Disposal, Switzerland, the Food and Agriculture Organisation of the United Nations, the USEPA and many academic institutions throughout the world to provide a sound epidemiological basis from which to formulate wastewater reuse guidelines. Their conclusions were that the actual risks associated with irrigation of treated wastewater is much lower than previously thought. This led to WHO (1989) producing guidelines that were less stringent than other internationally recognised guidelines. Shuval et al. (1986a; 1986b: 191 & 1986c: 147) on behalf of WHO, conducted an indepth review of epidemiological evidence, that included developing countries, to evaluate the health risks in using wastewater for agriculture. His results are discussed in Section 4.3.4.2.2.

4.3.4.2.2 *Epidemiological Studies of Wastewater Reuse Schemes*

One of the largest studies of the health effects of wastewater irrigation was a retrospective study of infections from aerosols in 207 kibbutzim in Israel where non-disinfected stabilisation pond effluent was used for crop irrigation (Katzenelson et al. 1976). The incidence of typhoid fever, salmonellosis, shigellosis and infectious hepatitis was reported to be 2–4 times higher in the land-treatment systems than in the controls. The study came under some criticism because it did not rule out a number of pathways of infection other than aerosols and there were problems with the data reporting methods, so it was generally considered to be inconclusive (Kowal et al. 1981: 329). As a consequence, this study was repeated by Shuval and Fattal (1980). Shuval et al. (1987) reported no excess enteric disease morbidity in the total population exposed to wastewater aerosols after carefully screening medical record data from 20 communities representing 10 000 people. However, they did mention that a higher enteric disease rate was found among children in the 0–4 age group during the irrigation season (Fattal et al. 1986: 977).

Yoram Avnimelech (1993: 1280) and Sattar and Ijaz (1987: 89), after reviewing available literature and a study in Texas (Camaan & Moore 1987), also failed to find any association between wastewater aerosol exposure and acute viral illness.

A Colorado Springs epidemiological study from 1984 to 1987 of the health effects associated with wastewater irrigation on public parks found no evidence of enteric illness associated with reclaimed irrigation water use (Allison et al. 1988, Schwebach et al. 1988: 473 & Durand & Schwebach 1987: 271). Notably, wet grass conditions were significantly correlated with an increase in gastrointestinal illness regardless of the quality of irrigant used (Durand & Schwebach 1989: 1659).

In regard to domestic non-potable effluent reuse in the USA, dual potable/reclaimed systems have been in use for over 20 years. The effluent quality has been high with very low numbers of faecal coliforms and viruses. One epidemiological study failed to detect any increase in enteric diseases in the communities using reclaimed water (Camp, Dresser & McKee 1987), even when a family consumed reclaimed water for six weeks after deliberately cross connecting reclaimed water to a potable connection!

Shuval et al. (1986a) reviewed all the available epidemiological studies on the agricultural use of wastewater. Their summary is as follows:

1. Crop irrigation with raw wastewater causes marked increases in intestinal infection of nematodes in both consumers and farmers when the helminths are endemic, especially barefoot workers;
2. Crop irrigation of treated wastewater, however, bears no significant excess risk;
3. Cholera and possibly typhoid can be transmitted via irrigation of vegetables with untreated wastewater;
4. The actual risk of beef tapeworm from irrigated effluent is poorly documented but still potentially exists;
5. Only very limited evidence exists for people living near raw wastewater irrigated fields being adversely affected by coming into contact with the soil or by secondary contact with farm labourers, if they maintain high standards of personal hygiene;
6. Actual risk of disease resulting from aerosolised viral and bacterial infection via sprinkler irrigation of treated wastewater has not yet been encountered. Rodie (1994: 266) states that the data on the true impact on public health on windblown aerosols will take years to accumulate and will be quite costly to obtain.

WHO concludes their epidemiological survey with a table, reproduced with slight modification, below, summarising the relative health risks from the use of untreated excreta and wastewater in agriculture and aquaculture, highlighting that intestinal nematode infection carries the highest risk:

Type of pathogen/infection	*Excess frequency of infection of disease*
Intestinal Nematodes Ascaris spp Trichuris spp Hookworms	High
Bacteria Bacterial diarrhoeas (eg cholera, typhoid)	Lower
Viruses Viral disease Hepatitis A	Lowest
Trematodes and cestodes (via aquaculture)	From high to nil, depending on the method of excreta use and local circumstances

Source: WHO 1989: 35

TABLE 4.12 Relative health risks from the use of untreated excreta and wastewater in agriculture and aquaculture.

Protozoa were not included in Table 4.12 as sufficient epidemiological data was not available at the time. Major recent outbreaks of giardiasis due to contaminated water supplies in developed countries strongly suggests *Giardia* has a high risk of infection via wastewater reuse schemes, although this has yet to be demonstrated.

Blumenthal et al. (1992) conducted epidemiological test in an agricultural scheme in Mexico to test the validity of the WHO (1989) guidelines. Preliminary analysis of the wet season data indicated that the risk of *Ascaris* infection and diarrhoeal disease to farm workers and their families was removed when effluent utilised from a storage dam met the WHO criteria.

4.3.4.3 Dose Response Models

Dose response models have been developed to predict the likelihood of infection after a person receives a dose of treated wastewater containing low levels of pathogens. This obviates the need to continually conduct dose-response studies for each exposure scenario. These models use dose-response curves derived from human feeding studies.

Charles Haas (1983a & b) developed probability of infection models that best fit the known dose-response data using either a beta-poisson model described as follows (Regli et al. 1991: 77–78; Asano et al. 1992: 1519–20):

$$P = 1 - (1 + \frac{N}{\beta})^{-a}$$

P is the probability of infection due to ingesting N number of organisms, α and β are the dose-response parameters for each organisms as listed in Table 4.13.

or an exponential model:

$$P = 1 - e^{(-Nr)}$$

P and N are as defined above r is the dose-response parameter for a particular organism listed in Table 4.13.

Organism	*Best Model*	*Model parameters*
Echovirus 12	beta-poisson	α = 0.374 β = 186.69
Rotavirus	beta-poisson	α = 0.26 β = 0.42
Poliovirus I	exponential	r = 0.009102
Poliovirus II	beta-poisson	α = 0.1097 β = 1524
Poliovirus III	beta-poisson	α = 0.409 β = 0.788
Giardia	exponential	r = 0.02
Entamoeba	beta-poisson	α = 0.128 β = 0.581

Source: Regli et al. 1991

Table 4.13 Probability of infection models and best fit dose-response parameters for various feeding studies

If N is not known then it can be estimated from knowing the concentration of pathogens at any point in the treatment train or environmental media and the efficiency of pathogen removal in the treatment process or die-off in the environment from this point to the place of exposure. This can be described by the following equation:

$$N = V_1.c_o\ (f_1 \times ..f_n)$$

V_1 is the volume of water ingested in a single day,
f_1,....., f_n are the fractions of pathogens remaining after the first, and nth treatment process or after environmental removal, c_o is the concentration of pathogens entering the first treatment process.

The fate of pathogens in the environment can be modelled by a first order decay equation which estimates the fraction of pathogens remaining after a certain period, t:

$$f = c/c_o = \exp(-kt)$$

f is the fraction of pathogens remaining
c is the concentration of pathogens remaining after period t,
c_o is the initial concentration of pathogens and k is the decay coefficient that is specific to each pathogen.

The risk of infection can be calculated on a daily, monthly, yearly or lifetime basis. Haas (1983a) used the following equation to extrapolate daily risk to a longer term risk as follows:

$$P_t = 1-(1-P_o)t$$

P_o is the probability of infection after one day of exposure to the hazard,
P_t is the probability of infection after t days of exposure and t is measured in days.

This Quantitative Risk Assessment process is very useful in estimating the actual risk attributed by adherence to guidelines limits set by government agencies and how much those risks would decrease or increase if these authorities were considering either a costly improvement or a relaxation of treatment technology.

4.3.5 Risk Characterisation

After the QRA data has been collected for levels of pathogens detected in wastewater and dose response models for these pathogens have been developed, a risk of infection can be calculated for a particular exposure scenario. Rose (1993: 9) listed risks of infection for ingestion of 100 mL of treated wastewater of various qualities based on QRA data as reproduced in Table 4.14.

Degree of Treatment	*Levels of pathogens/100 L*	*Exposure per 100 mL*	*Rotavirus*	*Echovirus*	*Giardia*
Secondary	130	0.13	0.068	$2.6x10^{-4}$	
Secondary	10	0.01	0.0061	$2.0x10^{-5}$	
Secondary	11.4	0.0114			$2.3x10^{-4}$
Secondary plus filtration	0.5	0.0005	$3.1x10^{-4}$	$1.0x10^{-6}$	
Secondary plus filtration	0.03	$3x10^{-5}$	$1.9x10^{-5}$	$6x10^{-8}$	
Secondary plus filtration	<1	<0.001			$<1.9x10^{-5}$

Source: Rose 1993

TABLE 4.14 Risk of infection from ingestion of 100 mL of wastewater of varying quality

The benchmark figure for acceptable risk in the USA is considered to be one infection per year per 10 000 people, ie, $1x10^{-4}$ risk. Secondary treatment with filtration will reach these levels for most pathogens but not for the more infectious agents like rotavirus. Nevertheless, in most TSE reuse operations, the likelihood of ingesting 100 mL is very unlikely except in the case of recreational swimming.

4.3.5.1 Two Case Studies of Risks Associated with Exposure to Viruses in Publicly Accessible Reuse Schemes

4.3.5.1.1 Case study of playing on a golf course

Asano et al. (1992) firstly used the QRA procedure for likely risks of infection for golfers on a wastewater irrigated golf course and based their analysis on a more realistic dose of 1 mL of wastewater ingested for each round of golf rather than on 100 mL.

They used the β-dose response model to calculate the risk associated with exposure to different concentrations of viruses in the wastewater used. Assumptions made were that the golfer uses the course twice a week for 30 years and each time ingests 1 mL of

wastewater through handling and cleaning golf balls. This adds up to 3 120 days of total exposure. It was also assumed that irrigation occurs during the night and that golfing occurs on a dry field resulting in the pathogens being inactivated after one day.

4.3.5.1.2 Case study when consuming effluent irrigated food crops

Secondly, 10 mL of reclaimed wastewater was assumed to be left on crops to be eaten raw and then withheld for the 14 days before harvest. Virus dieoff due to desiccation and sunlight over this time was included in the calculation.

The enteric database used for these two case studies includes 424 secondary effluent samples and 814 tertiary effluent samples obtained in California over the period 1975–1989 making it the largest database in the USA, and probably the world. Enteric viruses were detected in 45 to 87% of unchlorinated secondary effluents with a geometric mean ranging from 2–200 vu/100 L.[13] No native viruses were isolated in the chlorinated tertiary effluents except in a few that had design and operational difficulties (Asano et al. 1992: 1516).

The 424 unchlorinated secondary treated effluent samples gave an upper 90th percentile range of 500 vu/100 L and a maximum concentration of 73 400 vu/100 L. If this effluent is treated to a tertiary level as described by Asano et al. (1992) in Section 4.3.2.4 with an assumed 5 log removal based on studies then the above concentrations reduce to 0.005 vu/100 L and 0.734 vu/100 L in the effluent. Of the 814 tertiary effluent samples collected, enteric virus concentrations in the effluent were found to range between 1 to 111 vu/100 L, where the lower figure is the limit of detection. Results for both these case studies for daily, annual and lifetime risks of one infection for exposure to echovirus 12, poliovirus 1 and poliovirus 3 are presented in Figure 4.4.

From these graphs it can be seen that exposure to chlorinated tertiary effluent irrigated on a golf course containing 1 vu/100 L has an associated risk in the range of 1 in 100 to 1 in 10^7 per year per person exposed while exposure resulting from food crop irrigation results in an associated risk in the range of only 1 in 10^6 to 1 in 10^{11} (Asano et al. 1992: 1523). From the QRA, poliovirus 3 is the most infective of the three viruses.

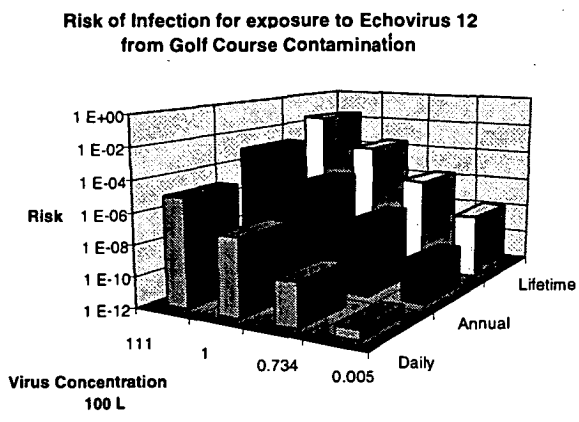
[13] vu = viral unit

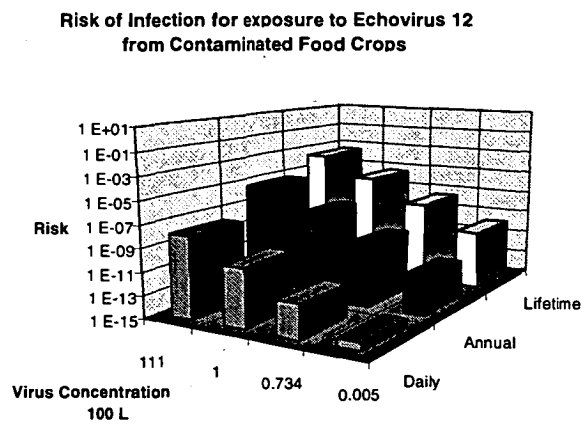
From the QRA case studies it is anticipated that unrestricted recreational impoundments used for swimming carried the highest probability of infection followed by landscape irrigation of golf courses and then spray irrigation of food crops.

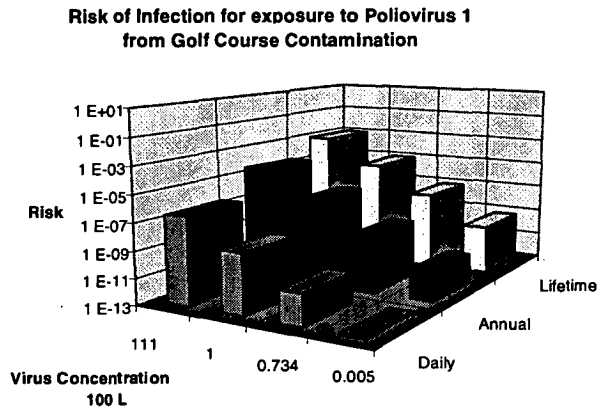
In the case where wastewater is only secondary treated, disinfected and then applied to a golf course a QRA has been calculated for high risk pathogens based on the results of the case study and is presented in the discussion of the case study (Chapter 8).

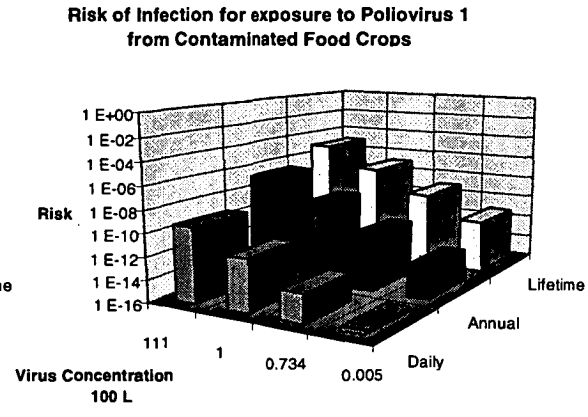
One critical flaw with the QRA process is the lack of information on typical pathogen levels in treated sewage effluent, pathogen fate in the environment and the reliability of the STP (Rose 1993: 11). This is particularly so in Australia where very limited data are available, some not in the public domain, on pathogens levels in STP effluent. QRA on Australian reuse schemes at present can only rely on international data, which does not take into account local conditions.

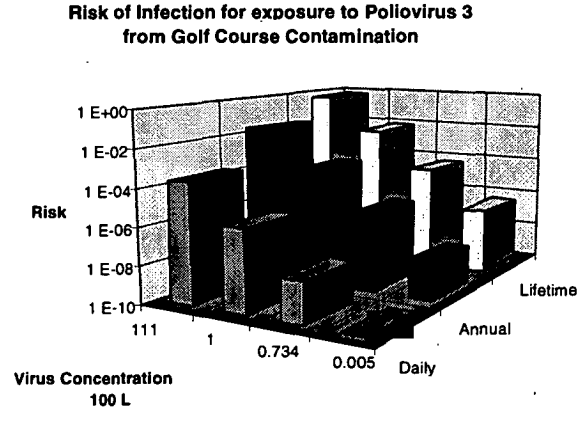
As we begin to see a rapid increase in the adoption of reuse schemes nationwide a more robust QRA database is needed to ensure risk estimates are valid. The case study that follows attempts to in part address this shortfall by providing information on the survival of faecal microorganisms in the environment in the context of greenspace irrigation.











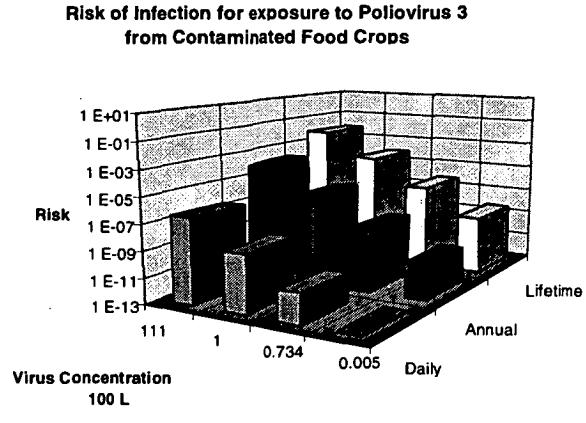


FIGURE 4.4 Daily, annual and lifetime risks of exposure to echovirus 12, poliovirus 1 & 3 from golf course and food crop contamination

4.4 The Development of Guidelines and Regulations

4.4.1 Introduction

Water reuse regulations and guidelines serve mainly to provide public health protection but they also provide consistency in the planning and operation of reuse schemes. Past cases of illness associated with application of raw or poorly treated wastewater and the fear of litigation have in the past provided the impetus for implementing quite stringent microbial standards (Crook 1994: 60; Wilkins & Anderson 1991: 32). The knowledge that regulations and guidelines are in place also increases public confidence in reuse schemes (Crook 1994: 57). The stipulations set forth in these will vary from country to country and within a country depending on the perspectives of each regional authority.

Regulations differ from guidelines in that they are established by a legislative authority as mandatory requirements to which a supplier and/or user of reclaimed water must adhere. Guidelines serve to provide a code of practice or conduct that are advisory, voluntary and therefore non-enforceable. James Crook (1994: 58), senior sanitary engineer with the Californian Department of Health Services (DOHS), prefers regulations instead of guidelines because they ensure compliance with safe management practices. However regulatory authorities have moved away from a regulatory approach to a more advisory role that seeks to elicit cooperation and partnership from local government and reuse scheme managers. Therefore, the following discussion will specifically refer to guideline unless otherwise indicated.

Concerning agriculture and irrigation schemes, guidelines will normally cover several issues relevant to the successful longterm operation of a reuse scheme. In addition to the protection of public, they provide guidance for the establishing of environmentally and economically sustainable reuse schemes. These guidelines usually specify: environmental protection measures for the irrigated land, aquifer and surface run-off; the need to provide clear management and operational procedures and trained staff; and the level of treatment, depending on the application intended (Crook 1994: 57; Cort 1987: 40; Rodie (1994: 266). Because of the multifaceted nature of reuse schemes, drafting of guidelines may be conducted by more than one agency. In Australia, state and national departments of the environment, public health and primary industry may conjointly produce various reuse guidelines. Alternatively, a committee may be

formed to produce guidelines for a particular end use, such as, the production of non-potable urban reuse guidelines for NSW (NSW RWCC 1993).

4.4.2 Survey of International Guidelines and Regulations

4.4.2.1 Introduction

Overseas guidelines for reclaimed water vary in content and complexity although they generally focus on protecting public health. In particular, two guidelines have essentially formed the basis for all worldwide guidelines currently in place: the California 1978 regulations, on which the USEPA (1992) guidelines refer to, and the WHO (1989) guidelines (NHMRC et al. 1996: 10).

Most of the overseas guidelines and regulations have been developed in the United States and therefore discussion will initially focus on them. Historically, regulations were only developed on a state by state basis, particularly where reuse was widely practiced, for example in California, Arizona, Texas and Florida. Only recently has the federal USEPA seen the need to produce nationwide guidelines (Crook 1994: 54).

Federal legislation in the USA as far back as the 1970s had encouraged the development of land application systems. By 1984, 31 states in the USA had issued guidelines or regulations for wastewater reuse with the objective of deriving maximum benefit from reclaimed water whilst protecting the environment and public health (USEPA 1992: 123; Forster & Southgate 1984: 401). By 1992, 18 states had some form of water reuse regulation and a further 18 had some form of guidelines, making a total of 36. The majority of these state guidelines and regulations refer to both urban and agricultural wastewater reuse. Reuse criteria tend to be more complete and stringent where the numbers of reuse schemes are growing (USEPA 1992: 124; Crook 1994: 63).

A brief review of the more significant state regulations is compared and discussed as follows:

4.4.2.2 Arizona

Arizona is the only state that has criteria for limits on viruses and round worms as well as for bacteria although their regulations do not specify a required treatment process. Nevertheless, these regulations are under review and it is likely the viral and parasitic criteria will be dropped, possibly due to the expense needed to carry out monitoring for

these pathogens and the unreliability of current testing methods (USEPA 1992: 127; Wilkins & Anderson 1991). They also stipulate other control measures, such as, no effluent spray shall reach privately owned premises, food establishments, or drinking fountains (Arizona Administrative Code). Their latest draft models more closely the USEPA (1992) *Guidelines for Water Reuse* (Crook 1994: 66).

4.4.2.3 California

California has long recognised the benefits associated with wastewater reuse particularly as a water conservation measure and has had the earliest water recycling regulations dating back to 1918. Encouragement for implementing reuse measures has been expressed in state legislature:

> "it is the intention of the legislature that the state undertake all possible steps to encourage development of water reclamation facilities so that reclaimed water may be made available to help meet the growing water requirement of the state." ("The Porter-Cologne Water Quality Control Act" 1985)

Further statutes added to the Act prohibited the use of potable water for non-potable uses when non-potable water was available.

The 1978 *Wastewater Reclamation Criteria,* promulgated by the Californian Department of Health Services (DOHS), are quite comprehensive in their coverage and have been used by other states and countries as a basis for their own regulations or guidelines (Asano et al. 1992: 1513, Crook & Okun 1987). The DOHS criteria include water quality standards, treatment process requirements, operational, and treatment reliability requirements thus providing a multibarrier approach towards public health protection (Crook 1994: 66, Crook & Okun 1987: 238). Treatment reliability requirements include: standby power supplies, standby treatment process units, emergency storage or disposal, bypassing, monitoring devices and automatic controllers (Crook 1994: 70).

The DOHS regulations rely on high treatment standards as a precautionary approach due to the lack of epidemiological studies on effluent reuse available at the time. Depending on the proposed use and hence the degree of human contact two standards of the maximum allowable median number of total coliforms, 23 cfu/100 mL or 2.2 cfu/100 mL, are specified for the effluent (Table 5.1). The lower figure was based on tertiary treated effluent that was essentially free of pathogens after recognising the potential for very low numbers of viruses to cause an infection (Crook 1994: 69).

Even though these standards are very strict, and as such, require high plant treatment levels and reliability, they nevertheless reflect the current wastewater treatment practice in California. The treatment required to reach the lower total coliform concentration requires the secondary treated effluent to be oxidised, coagulated, filtered and disinfected (Crook 1994: 67, 69).

Type of Use	*Total Coliform Limits*	*Treatment Required*
Fodder, Fibre and Seed Crops Surface Irrigation of Orchards and Vineyard	-	Primary
Pasture for Milking Animals Landscape Impoundments Landscape Irrigation (Golf Courses, Cemeteries, etc...)	23/100mL	Oxidation and Disinfection
Surface Irrigation of Food Crops Restricted Recreational Impoundments	2.2/100mL	Oxidation and Disinfection
Spray Irrigation of Food Crops Landscape Irrigation (Parks, Playgrounds, etc.) Nonrestricted Recreational Requirements	2.2/100mL	Oxidation, Coagulation, Clarification, Filtration[a], Disinfection
Groundwater Recharge	Case-by-case evaluation	Case-by-case evaluation

Source: State of California, 1978 cited in Crook 1994: 68.

[a] Turbidity of filtered effluent cannot exceed an average of 2 turbidity units during any 24-hour period

TABLE 5.1 California treatment and quality criteria for reuse

In regard to publicly accessible landscape irrigation, including irrigation of golf courses, the total coliform criterion for the effluent is <23 cfu/100 mL in rural areas whereas in urban areas it is <2.2 cfu/100 mL, where spray drift into neighbouring residences is of concern. Other conditions of off-hours irrigation and ensuring no wind drift of aerosols to neighbouring residences also apply.

With the ever widening range of reuse opportunities, considerable efforts have been undertaken to revise the existing criteria. To this end, Asano et al. (1992: 1514) analysed available data on enteric virus levels in secondary and tertiary effluent and conducted a quantifiable health risk assessment on four scenarios of public contact with treated effluent. Two of these scenarios were discussed in Section 4.3.5.

4.4.2.4 Florida

In the early 1980s, Florida developed regulations for reuse and land application of municipal effluent entitled *Land Application of Domestic Wastewater Effluent in Florida.* Irrigation of public places such as golf courses and irrigation of edible crops were permitted but requirements for these activities were incomplete. An updated code called the *Reuse of Reclaimed Water and Land Application* was adopted and revised in 1990. Their treatment criteria are reproduced in Table 5.2.

Type of Use	*Allowable Limits*	*Treatment Required*
Restricted Public Access Areas[a]	200 Faecal Coli/100 mL 20 mg/L TSS	Secondary 20 mg/L BOD Disinfection
Public Access Areas[b] Food Crop Irrigation[c] Toilet Flushing[d] Fire Protection Aesthetic Purposes Dust Control	No detectable Faecal Coli/100 mL 5 mg/L TSS 20 mg/L BOD	Secondary Disinfection Filtration
Rapid Rate Land Application	200 Fecal Coli/100 mL 20 mg/L TSS 20 mg/L BOD 12 mg/L Total N	Secondary Disinfection

[a] Sod farms, forests, fodder crops, pasture land, or similar areas.
[b] Residential lawns, golf courses, cemeteries, parks, landscaped areas, highway medians, or similar areas.
[c] Only allowed if crops peeled, skinned, cooked or thermally processed before consumption.
[d] Not allowed where residents have access to plumbing system.
Source: State of Florida 1990

TABLE 5.2 Florida treatment and quality criteria for reuse.

In addition to water quality and treatment requirements, Florida also stipulated design and use requirements that cover the size of the scheme, emergency storage facilities, plumbing requirements similar to the Californian regulations, around the clock staffing, measures to ensure no effluent leaves the use area, public notification and setback distances (Crook 1994: 71). Florida's regulations are similar in strictness to the Californian regulations in that no FC/100 mL may be detected in effluent used for publicly accessible areas. Total suspended solid (TSS) limit is partly to ensure pathogen destruction during disinfection.

Florida also has a mandatory reuse program in critical water supply areas for wastewater treatment facilities unless such reuse is economically, environmentally and technologically not feasible (Crook 1994: 71).

4.4.2.5 Texas

Texan regulations do not specify wastewater treatment processes and water quality standards are less strict than those in California and Florida. For restricted landscaped areas 800 FC/100 mL are allowable with a corresponding BOD of 20 mg/L taken over a 30 day average. These standards apply at the point of use and not at exit from the treatment plant. For unrestricted access, faecal coliforms must be less than 75 cfu/100mL with corresponding limits for turbidity and BOD. The faecal coliform level is the same for food crops not eaten raw. Texas, as with Florida, has in place some controls affecting the operation of the reuse scheme. Contracts are required between supplier and user of wastewater in order to identify their respective responsibilities and liabilities (Crook 1994: 78).

4.4.2.6 United States Environment Protection Agency Guidelines

In 1992, the USEPA produced *Guidelines for Water Reuse* in consultation with technical advice received from more than 50 nationally and internationally recognised public health experts. The USEPA preferred to initially produce guidelines rather than regulations in order to provide a basis from which more comprehensive state or federal standards could be developed (USEPA 1992: 123). These are principally directed at the protection of public health by specifying an assortment of controls for pathogen reduction. They also provide an inventory and comparison of state regulations and guidelines. Their scope is focussed on domestic municipal waste containing little industrial input and covers all forms of reuse except potable reuse (USEPA 1992: 132). These guidelines tend to be fairly conservative, requiring high-technology driven and expensive treatment processes (NHMRC et al. 1996: 10). This approach is based on reuse experience in the United States, results of research and pilot studies, technical reviews, other state regulations, attainability and sound engineering practice.

USEPA philosophy is to recommend a multibarrier approach by specifying treatment processes and reliability provisions, water quality limits, monitoring programs, set back distances and other controls particular to the reuse area (Crook 1994: 79). Water quality parameters are the median concentration of faecal coliforms, turbidity and suspended solids. They include both treatment train and water quality recommendations to obviate the need to monitor for pathogens such as viruses because of the difficulties involved (USEPA 1992: 139).

All forms of reuse that have a degree of public access specify filtration requirements which aid in the reduction of the larger parasites. This practice does not appear to be widely used in Australia or recommended in Australian guidelines for publicly accessible reuse schemes, such as greenspace irrigation (USEPA 1996: 133). Secondary treatment and disinfection have very little effect on parasite reduction and therefore may present a problem in Australia as reuse schemes expand.

With regard to golf course irrigation, the guidelines recommend secondary treatment, filtration and disinfection producing an effluent with no faecal coliforms per 100 mL and a chlorine residual of 0.5 mg/L. In addition, the following recommendations are suggested by the US Golf Course Architects Association (Gill & Rainville 1994: 51) to protect public health:

- Drinking fountains to have a self closing cover or to be relocated;
- Signs should indicate "reclaimed water used to irrigate turf";
- When installing pipelines use warning tape with the distinctive colour purple;
- The distance between these lines and potable water lines should be 3 m horizontally and 30 cm below where they cross; and
- Installing low pressure sensors to shut down the system in the event of pressure failures.

4.4.2.7 World Health Organisation Guidelines

A controversial and yet a fairly comprehensive set of guidelines was produced in 1989 as a result of a meeting by a WHO scientific group, representing developed and developing nations, held in Geneva in 1987 titled, *Health guidelines for the use of wastewater in agriculture and aquaculture* (WHO 1989). These guidelines deal primarily with municipal wastewater for urban greenspace irrigation, fish culture, orchard and vineyard irrigation, fodder, fibre and seed crop irrigation, and irrigation of crops both consumed raw and consumed after processing (WHO 1989: 5, 15).

The guidelines were designed to be realistically achievable on an international basis. Therefore a balance was sought, on the one hand to establish guidelines which adequately protect both the environment and public health whilst, on the other hand, to recommend measures that would be feasible in countries where the infrastructure or economy place limitations on control measures available.

In the past 50 years, stringent biological standards for wastewater reuse were adopted in many countries that enjoyed high levels of public health protection. With a lack of knowledge of the real health risks and the wide adoption of unenforceable standards, poorer countries have been encouraged to believe that reuse of effluent for irrigation is too costly. This has either resulted in a failure to adequately plan for wastewater reuse or the uncontrolled use of untreated or treated sewage by farmers (WHO 1989:10-11).

In an attempt to address this dilemma, WHO placed much greater emphasis on epidemiological studies as the basis for formulating guidelines in contrast to the earlier regulations produced in the United States. From this evidence, the Engelberg report recommended new guidelines that contained less stringent standards for faecal coliforms than had been previously suggested whilst recommending stricter limits on helminth eggs allowable in recycled effluent where they are endemic (WHO 1989: 7, 11). In addition, by specifying measures to remove helminths, WHO (1989: 39) believed protozoan cyst removal would also occur to a similar extent. The WHO scientific group adopted these standards in the 1989 guidelines and are reproduced in Table 5.3. WHO (1989: 49) specifies three categories of reuse (Table 5.3):

1. Category A is the highest recommended quality of wastewater for reuse where public health protection is most critical;
2. Category B requires protection of the agricultural workers only; and
3. Category C where no exposure takes place.

WHO stress the need for a more integrated approach to planning that takes into account local socio-cultural, institutional and economic conditions. They recommend that emphasis must be placed on careful selection and design of treatment plants that do not require a high degree of care in operation nor continuous monitoring programs, particularly in countries that have poor infrastructure. They also recommend proper education of the user in understanding why crop restriction is necessary and to be assisted in developing a wastewater reuse program that ensures the maintenance of health protection standards (WHO 1989: 50).

WHO (1989: 40) provide several plausible reasons apart from epidemiological evidence for relaxing the faecal coliform standard for unrestricted irrigation:

- natural die-off of pathogens will continue to occur due to UV irradiation, desiccation and natural predators once the effluent is applied to the crop and soil often providing a further reduction of 90-99% within a few days;

- studies of wastewater effluent containing 1 000 cfu/100 mL contained usually few, if any, detectable pathogens; and,
- these guidelines match the actual quality of river water used for unrestricted irrigation of all crops in many countries without any known ill effects[1].

Category	Reuse conditions	Exposed group	Intestinal nematodes[b] (eggs/litre[c] arithmetic mean)	Faecal coliforms (FC/100 mL geometric mean)	Wastewater treatment expected to achieve the required microbiological quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[d]	Worker, consumers, public	≤1	≤1 000	A series of stabilisation ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[e]	Workers	≤ 1	No standard recommended	Retention in stabilisation ponds for 8–10 days or equivalent helminth and faecal coliform removal
C	Localised irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

Source: WHO 1989: 39

[a] In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account, and the guidelines modified accordingly.

[b] *Ascaris* and *Trichuris* species and hookworms.

[c] During the irrigation period.

[d] a more stringent guideline (≤200 faecal coliforms per 100 mL) is appropriate for public lawns, such as hotel lawns, with which the public may come into contact.

[e] In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

TABLE 5.3 Recommended microbiological quality guidelines for wastewater use in agriculture[a]

The philosophy behind the guidelines is to use a combination of health protection measures each of which need not be absolutely foolproof, rather than focussing solely

[1] About 45% of rivers around the world have concentrations of 1 000 FC/100 mL or more. Data for Africa was not included (Global Environmental Monitoring System, *Global pollution and health. Results of health-related environmental monitoring*, Geneva, WHO/UN Environment Program, 1987).

on one measure. This enables optimising investment costs whilst adequately protecting public health (WHO 1989: 35, 53). WHO identified four main measures or barriers that can be taken to protect health:

1. Partial or full treatment of the wastewater;
2. Restricting the type of crop used, that is Category B;
3. Irrigation application techniques; and,
4. Human exposure control.

Human exposure controls for the high risk groups, such as workers and neighbouring residents include (WHO 1989: 52):

- wearing of protective clothing (not barefoot);
- immunisation, particularly against typhoid and hepatitis A;
- basic hygiene, particularly washing hands before eating or putting hands to mouth;
- chemotherapeutic control (medical drug treatment after infection to ensure no disease symptoms);
- adequate cooking of food treated with effluent along with good hygiene practices;
- informing local residents of the presence of effluent reuse schemes in order to prevent them from inadvertently entering them. WHO suggest a 50-100 m buffer zone between schemes and houses or roads;
- measures to prevent inadvertent drinking of the wastewater, such as clear signposting to warn people, adequate provision of potable water, clearly marked piping, etc...

When crop restriction is introduced the consumer is protected but not the worker, whereas control over the method of application can protect both worker and consumer. Alternatively, when full treatment of the wastewater is utilised, that is, Category A wastewater, comprehensive protection is enhanced.

Nevertheless, these measures employ one treatment barrier only and may provide inadequate protection when it is not complied with due diligence in countries lacking regulatory control. Partial treatment, along with other measures, will deal to some extent with the risk at the source thus reducing the possibility of exposure at the point of use and may in some instances be acceptable to all parties. For example, partial

treatment with crop restriction or application measures can significantly reduce the risks to both farm workers and consumers without the requirements of full treatment whilst at the same time being less prone to lack of regulatory control. WHO concludes that the optimum combination of measures will depend on local conditions and the specific groups of people to be protected (WHO 1989: 53-56).

4.4.3 Survey of Australian National and State Guidelines

In Australia where full treatment practices are the norm and the necessary infrastructures and regulatory controls are in place, the partial treatment option may not be acceptable or necessary although a multibarrier approach can be achieved without excessive added cost whilst ensuring more substantial public health protection.

This section will discuss the various Australian guidelines, national and state, by highlighting their aims, scope, focus and measures recommended for the protection of public health and how they refer to other international guidelines.

Public health aspects of the use of reclaimed water in Australia essentially come under the control of state and territory public health and environment protection departments (GHD 1983: 5). Nevertheless, the Federal Government plays a role in coordinating state and federal issues. The Federal Department of Primary Industries and Energy provides oversight of national water management issues. The Federal Department of Environment, Sport and Territories (DEST) and the Environmental Protection Agency (EPA) are responsible for national environmental concerns and recently, the National Environment Protection Council involving the ministers of both levels has been established to ensure common approaches to environmental management (AWWA 1996a: 39).

The Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) and the Australian and New Zealand Environment Conservation Council (ANZECC) also seek to coordinate regional, national and state objectives in specific areas. ARMCANZ comprises ministers, federal and state, responsible for agriculture, soil conservation and water affairs and ANZECC, formerly the Australian Water Resources Council (AWRC), is a cooperative ministerial council involving the two countries. Both ARMCANZ and ANZECC have prepared water quality guidelines as part of a National Water Quality Management Strategy (AWWA 1996a: 39).

Guidelines of importance in Australia are listed as follows and are briefly reviewed:

1. National Water Quality Management Strategy, *Draft Guidelines for Sewerage Systems, Use of Reclaimed Water,* (NHMRC et al. 1996);
2. The New South Wales Draft Environmental Guidelines For Industry, *The Utilisation of Treated Effluent by Irrigation* (NSWEPA 1995);
3. NSW Recycled Water Coordination Committee, *NSW Guideline for Urban and Residential Use of Reclaimed Water* (NSW RWCC 1993);
4. Victorian Environmental Protection Authority, *Guidelines for Wastewater Irrigation,* (VICEPA 1991);
5. QLD Department of Primary Industries, *Guidelines for Planning and Design of Sewerage Schemes, Vol 2, Section 18.1 Land Disposal and Effluent Re-use,* (QLD DPIF 1992); and
6. Tasmanian Department of Environment and Land Management, *Guidelines for Re-use of Wastewater in Tasmania,* (DELM 1994).

All the guidelines promote the philosophy that wastewater reuse is to be viewed as a practice that beneficially and responsibly utilises a resource rather than as a form of disposing of waste. All are concerned with both ensuring environmental sustainability and the protection of public health although they vary in their focus and their scope. In particular, the National, NSW urban and Tasmanian DELM guidelines focus primarily on public health protection whereas the NSWEPA, VICEPA and QLD DPIF focus more heavily on environmental aspects.

With regard to public health protection, all promote a multibarrier approach, thus reflecting the WHO and USEPA guidelines. They typically specify water quality and treatment technology requirements, public exposure controls, stipulations for the distribution system, training of staff, well designed management and operational protocols and the inclusion of emergency backup systems. The degree of stringency in terms of water quality lies between the USEPA (1992) and the WHO (1989) guidelines.

4.4.3.1 National Water Quality Management Strategy (1996), *Draft Guidelines for Sewerage Systems, Use of Reclaimed Water*

The National Health & Medical Research Council (NHMRC), ANZECC, and ARMCANZ have collectively published draft guidelines in 1996 for the reuse of wastewater as part of a National Water Quality Management Strategy in Australia

(NHMRC et al. 1996). These guidelines supersede the 1987 NHMRC and AWRC guidelines.

The document seeks to provide national guidelines for the reuse of reclaimed water and is one of five documents related to sewerage systems. It sees itself as a reference for water managers, sewage authorities, community, industry and environment groups for the provision of safeguards for public health and the environment. It encompasses current knowledge and international practice as well as accommodating existing practices previously demonstrated to be safe and beneficial (NHMRC et al. 1996: 3). The guidelines do refer to the WHO, USEPA and the NSW RWCC urban guidelines. Their scope covers effluent from municipal STPs with largely domestic input and they deal with all forms of reuse except potable reuse which is not recommended.

The guidelines essentially focus on public health protection that covers the microbial aspects of water quality, forms of sewage plant treatment, safeguards and controls, and the monitoring and reporting water quality. They briefly cover the need for reuse scheme planners and managers to involve public consultation, consider legal requirements and establish contractual procedures. A small section is also devoted to environmental and management issues such as hydraulic and nutrient loads to be balanced with soil and crop uptake and the need to control salinity and toxic chemicals (NHMRC et al. 1996: 31). In addition they provide a description of the different types of reuse schemes and provide guidelines accordingly in the following areas:

- the required level of treatment;
- the effluent quality indicated by the median concentration of faecal coliforms, turbidity and suspended solids;
- monitoring programs; and
- control and safeguards.

These guidelines are reproduced in Appendix 11.

4.4.3.2 The New South Wales Draft Environmental Guidelines For Industry (1995), *The Utilisation of Treated Effluent by Irrigation*

The NSWEPA guidelines have three aims: to encourage beneficial use of effluents whilst being ecologically sustainable manner (in particular, it encourages the use of effluent for non-potable uses where potable water is presently being used); to provide guidance for planning, designing, operating and monitoring of reuse schemes in order

to minimise environmental degradation and risks to public health; and to outline approvals needed and licensing requirements (NSWEPA 1995: 1). The scope of the guidelines covers irrigation schemes only, such as crop, pasture and greenspace irrigation and no particular type of effluent is addressed. Urban reuse is covered by the NSW RWCC guidelines.

The guidelines major focus is on environmental sustainability of the scheme. They provide much detail on the design of a scheme in terms of hydraulic and nutrient loading rates that are commensurate with the crop concerned and soil types, site selection criteria, salinity and chemical checks. Of the 92 page document, 85 pages are devoted to environmental issues. Worked examples, meteorological data and a computer program are provided to assist a planner in designing a scheme. The NSW Department of Health produced guidelines titled, 'Reuse of Sewage Effluent in NSW: Guidelines for the Protection of Public Health' in 1985. They would negate the need for the EPA to dwell on the subject.

In terms of public health aspects 3 pages are devoted to the subject. For the type of reuse discussed that involves a degree of public exposure they specify a multibarrier approach that involves: a minimum of secondary treatment and disinfection; effluent quality limits based on the geometric mean concentration of FC or an equivalent pond detention period, total dissolved solids and BOD; public controls; withholding periods; crop selection criteria and irrigation method. They specify three grades of effluent that are prescribed for particular crops depending on the degree of public exposure (NSWEPA 1995: 14-16).

4.4.3.3 NSW Recycled Water Coordination Committee (1993), *NSW Guideline for Urban and Residential Use of Reclaimed Water*

The philosophy of these guidelines is the promotion of the beneficial use of reclaimed water, the need for comprehensive community consultation and the adoption of a multibarrier approach for public protection. Their scope is urban dual reticulation effluent for non-potable residential and urban reuse, such as garden and car washing, toilet flushing and greenspace irrigation. Because this is not in an agricultural setting and the degree of public contact is high the primary concern of these guidelines is the protection of public health. The effluent considered is municipal, with some industrial input.

The focus is on the microbiological, physical and chemical quality of the effluent, treatment requirements, monitoring and controls, emergency back up systems, recommended uses of the effluent, seasonal storage, distribution and on site system controls and system monitoring. The treatment process specified is based on the Californian and Florida models that includes tertiary treatment, coagulation, filtration, disinfection and pH adjustment (NSW RWCC 1993: 6-15).

In particular there are five strategies for public health protection:

- Water quality monitoring using coliforms, FC, viruses, parasites, turbidity and pH as quality parameters;
- Treatment requirements that include emergency backups, automation of monitoring certain parameters and disinfection criteria met before release of the water;
- High standard of operation, trained and professional staff;
- Control of water usage by clearly marking reclaimed water pipes and above ground facilities, backflow and cross connection protection for potable lines and warning signs; and
- thorough public education on user responsibilities.

4.4.3.4 Victorian Environmental Protection Authority (1991), *Guidelines for Wastewater Irrigation*

The Victorian EPA guidelines are very similar in focus and scope to the NSWEPA guidelines. Their main concern is that any reuse scheme should be environmentally sustainable (VICEPA 1991: 1-3).

The bulk of the 104 page document addresses site selection, water quality in relation to soil type and plant growth, land use and environmental management that involves pollution monitoring, water budgeting, groundwater and surface water protection and salinity control. Four pages are devoted to the public health issue.

For the protection of public health, the guidelines recommend at least secondary treatment and monitoring of water quality parameters, such as median value of FC concentration or equivalent pond detention, BOD and suspended solids, restrictions on permitted uses, warning signs and public exposure controls (VICEPA 1991: 39-42).

4.4.3.5 QLD Department of Primary Industries (1992), *Section 18.1 Land Disposal and Effluent Re-use*

Guidelines regarding effluent reuse are considered by the DPIF as a part of a wider sewerage management strategy whereby land disposal and reuse need to be considered as a total management process. Nevertheless, they make a distinction in the philosophy behind them both. That is, reuse is to be seen as a beneficial use of a resource and effluent disposal is to be seen as a form of waste disposal. Their scope encompasses agricultural and greenspace irrigation, recreational, industrial, urban, and domestic reuse, although they refer the reader to the NHMRC & AWRC 1987 guidelines (now superseded). These guidelines apply to treated municipal sewage only (QLD DPIF 1992: 1, 5).

Section 18.1 covers public health, site selection, legal issues, avoidance of surface and groundwater pollution, salinity, public consultation, chemical pollution, costing and design of a reuse scheme. Public health covers 1½ pages of the 28 page section. In particular, an interim schedule (QLD DPIF: 1992: 6) specifies sewage treatment, crop restriction, exposure controls, promotion of hygiene, warning signs, marking and separation of pipelines and taps from potable lines, notification of nearby residences and water quality controls. Depending upon the application, either a qualitative indication of water quality parameters are made in terms of bacteria, parasite or viral removal or a quantitative limit of faecal coliforms is recommended. Irrigation of effluent on crops eaten raw is not recommended and a faecal coliform limit is applicable to crops eaten cooked and primary recreational contact such as swimming or water skiing.

4.4.3.6 Tasmanian Department of Environment and Land Management (1994), *Guidelines for Re-use of Wastewater in Tasmania*

A wastewater coordination group made up of members from DELM, the Department of Community Services and Health, Department of Primary Industries and Fisheries and local government worked together in the production of these guidelines in recognition of the joint issues of public health, environmental management and agronomy practices. The guideline's philosophy behind wastewater reuse is largely based on the interstate guidelines that seeks to foster community awareness and a change of attitude towards viewing the effluent as a resource that can beneficially be utilised. Secondly, they encourage effluent reuse as a preferred option to discharge into waterways:

> The reuse of wastewater by application to land is preferred to discharge to receiving water, ***PROVIDED THAT*** it can be demonstrated that the scheme is sustainable in the long term, and will not adversely effect the subject land, the amenity of the surrounding land, surrounding waterways or underlying groundwater, ***AND PROVIDED THAT*** the public health can be adequately protected (DELM 1994: 1).

The guidelines only address publicly accessible forms of reuse. Potable, non-potable domestic and primary recreational reuse are not envisaged and therefore not considered. Effluent irrigation of crops consumed raw is not permitted (DELM 1994: 8). Only domestic municipal wastewater is considered here.

The focus of the guidelines is primarily on the public health issues as opposed to the other state guidelines. They also mention the approval process required, site selection, environmental sustainability issues, such as nutrient and hydraulic loading, water quality, management and operation guidelines. They are not as detailed as the NSWEPA and VICEPA guidelines although there are close similarities.

Recommendations for public health protection resemble to a large extent the NSWEPA guideline limits. The only difference is the doubling of lagoon detention times probably due to the cooler climate (DELM 1994: 11). They also recommend at least secondary treatment for landscape and agricultural irrigation and dust suppression. Water quality parameters to be monitored are faecal coliform concentrations (geometric mean and upper limit of five samples taken at half hourly intervals). BOD and suspended solids are also stipulated (DELM 1994: 11, 18). In addition, crop restriction, irrigation methods, and public exposure controls are specified, such as no above ground water outlets, signposting, withholding periods, clear marking of piping and protection of drinking fountains (DELM 1994: 9).

4.4.3.7 Interstate Comparison of Public Health Protection Guidelines for Restricted and Unrestricted Irrigation of Greenspaces

To provide an overview that compares the national and state guidelines Table 4.4 lists the water quality, sewage treatment and other control criteria for greenspace irrigation that has relevancy to the golf course effluent reuse scheme discussed in Part Two of the thesis.

Guideline	*Upper bacterial limit and treatment technology*		*Other Requirements.*
	Restricted Access	Unrestricted Access	
NHMRC, ANZECC &ARMCANZ (1996) draft guidelines	Median Value of <1 000 FC/100 mL Treatment Level Secondary with pathogen reduction (disinfection or ponding)	Median Value of <10 FC/100 mL Treatment Level Secondary with filtration and pathogen reduction	Effluent quality before disinfection: • Turbidity ≤2 NTU • Chlorine residual • >5 mg/L and >1 mg/L • pH 6.5–8.0
QLD DPIF (1992) Guidelines for	No figure Treatment level Secondary, sand filtration or 10 day ponding (sometimes required) and disinfection	No figure Treatment level Secondary, sand filtration or 10 day ponding (sometimes required) and disinfection	
Victorian EPA (1991) guidelines (Revised)	Median Value of <1 000 FC/100 mL and 90% of samples <2 000 FC/100 mL or 30 days retention at BOD <20 mg/L	Not Specified	• BOD median <50 mg/L • Suspended solids <50 mg/L
NSWEPA (1991) draft guidelines	Geometric mean < 750 faecal coli/100mL Treatment Level Secondary with disinfection or 20 day ponding	Not discussed They probably would not recommend it	
TAS DELM (1994) guidelines	As above except they recommend 40 day ponding	Not discussed	
USEPA (1992) guidelines	Median Value of £ 14 faecal coli/100mL Treatment Level Secondary with filtration and disinfection.	No detectable faecal coliforms Treatment Level Secondary with filtration and disinfection.	• pH in the range 6–9 • ≤10 mg/L BOD • ≤2 average NTU and not to exceed 5 NTU prior to disinfection or else suspended solids ≤5 mg/L • 1 mg/L chlorine residual.
WHO (1989) guidelines	Mean ≤1 000 FC/100 mL Treatment Level Series of stabilisation ponds	Mean ≤200 FC/100 mL Treatment Level Series of stabilisation ponds	
ANZECC 1992 Australian Water Quality Guidelines For Fresh and Marine Waters (primary contact)		Median Value of ≤150 FC/100mL	

TABLE 5.4 Comparison of national and interstate guidelines for restricted and unrestricted greenspace irrigation

In the table, two scenarios are presented:

- Restricted access irrigation, whereby the public is prevented from entering the effluent irrigated area during and after irrigation. An example of this is irrigating a golf course overnight while no golfers are present;
- Unrestricted access irrigation, whereby there are no controls set in terms of withholding the public during irrigation. An example of this is the case of municipal irrigation of a public park that has unrestricted hours of access.

There is a vast difference between the effluent quality required for restricted irrigation and that required for unrestricted irrigation. All the guidelines seem to confirm the need for very high effluent quality for unrestricted irrigation, to the point where there are very little or no detectable faecal bacteria. It is interesting that the ANZECC (1992) water quality guidelines allow swimming in water with a relatively poorer microbial water quality than that stipulated for unrestricted greenspace irrigation.

PART TWO

CASE STUDY: RIVERSIDE GOLF COURSE

CHAPTER 5

INTRODUCTION TO THE RIVERSIDE GOLF COURSE WASTEWATER REUSE SCHEME

5.1 Introduction

Part two presents an overview of the Riverside Golf Course reuse scheme, the experimental design of the case study, the results of the case study, discussion of these results and the implications and recommendations for future research and improved practices at golf courses in the temperate Australian climate.

5.2 Aim of the study

See Section 2.2 for the aim of the study.

5.3 Golf Course Exposure Analysis

This case study serves chiefly to provide information for the exposure assessment step of a risk assessment. Figure 5.1 was constructed to help identify microbial hazards and the potential pathways of pathogen infection throughout the golf course. It identifies each place or environmental medium, (see the text boxes in Figure 5.1), in which these pathogens may exist and the pathways by which they may be transferred to another medium or persons. The microbial hazard associated with each place or medium refers to the levels and virulency of the pathogens that may exist there (for brevity, the hazard will be defined as the place or medium where the microbial hazard exists). Whereas the risk associated with each hazard also depends on the potential degree of contact an individual may have with that hazard.

Therefore to determine the risk associated with a particular hazard in the golf course, both the type and prevalence of each pathogen and the degree of human exposure need to be identified.

Identification and enumeration of potential pathogens in secondary treated wastewater is an expensive process and beyond the scope of this case study, so other studies have to be relied upon for this information. To assess their potential prevalence when irrigated on a golf course, faecal coliforms are used as an indicator for these pathogens. Survival times of faecal coliforms on crops and in soil compare well with pathogens, such as: enteroviruses, pathogenic bacteria and protozoa under the same conditions (Feachem et al. 1983; Kowal et al. 1981). Thus their presence and

persistence provides a guide to the severity of a particular hazard. In addition, the use of faecal coliforms enables direct comparison with national and state wastewater reuse guidelines that use faecal coliforms as a basis for testing the acceptability of a reuse scheme in terms of public health. Observation of golfers, as well as golf course groundstaff, and their habits provide the information for the degree of human exposure.

Hazards and pathways of particular concern to golfers and ground staff have been identified by the shaded boxes in Figure 5.1. Therefore, the experiment was designed to enumerate FC/*E. coli* at each of these potential hazards the results of which will be compared with the following guidelines:

- Department of Environment and Land Management (DELM), 1994, *Guidelines for Re-use of Wastewater in Tasmania;*
- Australian and New Zealand Environment and Conservation Council (ANZECC), 1992, *Australian Water Quality Guidelines for Fresh and Marine Waters,* National Water Quality Management Strategy, Section 3.1.2 'Secondary contact'; and
- ANZECC, ARMCANZ & NH&MRC, 1996, *Guidelines for the use of reclaimed water - Draft,* National Water Quality Management Strategy.

There are three main routes of infection to the human body: ingestion via the mouth, inhalation through the nose or mouth, and infection via a break in the skin barrier. With regard to the recreational activity of golfing and the route of ingestion, the critical hazard that needs monitoring is the players' hands since there are at least three potential pathways of infection: via handling their golf balls, direct contact with the turfgrass and contact with their shoes; and possibly to a lesser extent, contact with their clubs, tees and drying towels which also contact the turfgrass, ball or clubs constitute other pathways. The golf ball makes regular contact with the turfgrass, so handling the ball presents a particularly high risk pathway of infection.

Once golfers hands are infected, they can pass on pathogens by putting their hand to their mouth or nose or by handling an object which they then put to their mouth, for example: food, a drink container, cigarette, pen or handkerchief. In particular, eating or drinking after a round of golf before washing their hands increasing their chances of infection.

Therefore, the sampling program included swabs of players' hands and taking rinse samples of their golf balls for the purposes of identifying the risks associated with these pathways of infection. In addition, from anecdotal evidence some golfers are predisposed to licking their golf balls which allows pathogens to bypass the hands straight to the mouth. Sampling of their shoes was not included due to the difficulty of taking samples that would not be swamped by external sources.

Aerosols were also monitored as a potential pathway of infection via the respiratory route on the golf course. In addition, soils were monitored for potential groundwater contamination of raw water supplies (although, on occasion, the groundstaff would dig holes in the soil thus risking momentary exposure).

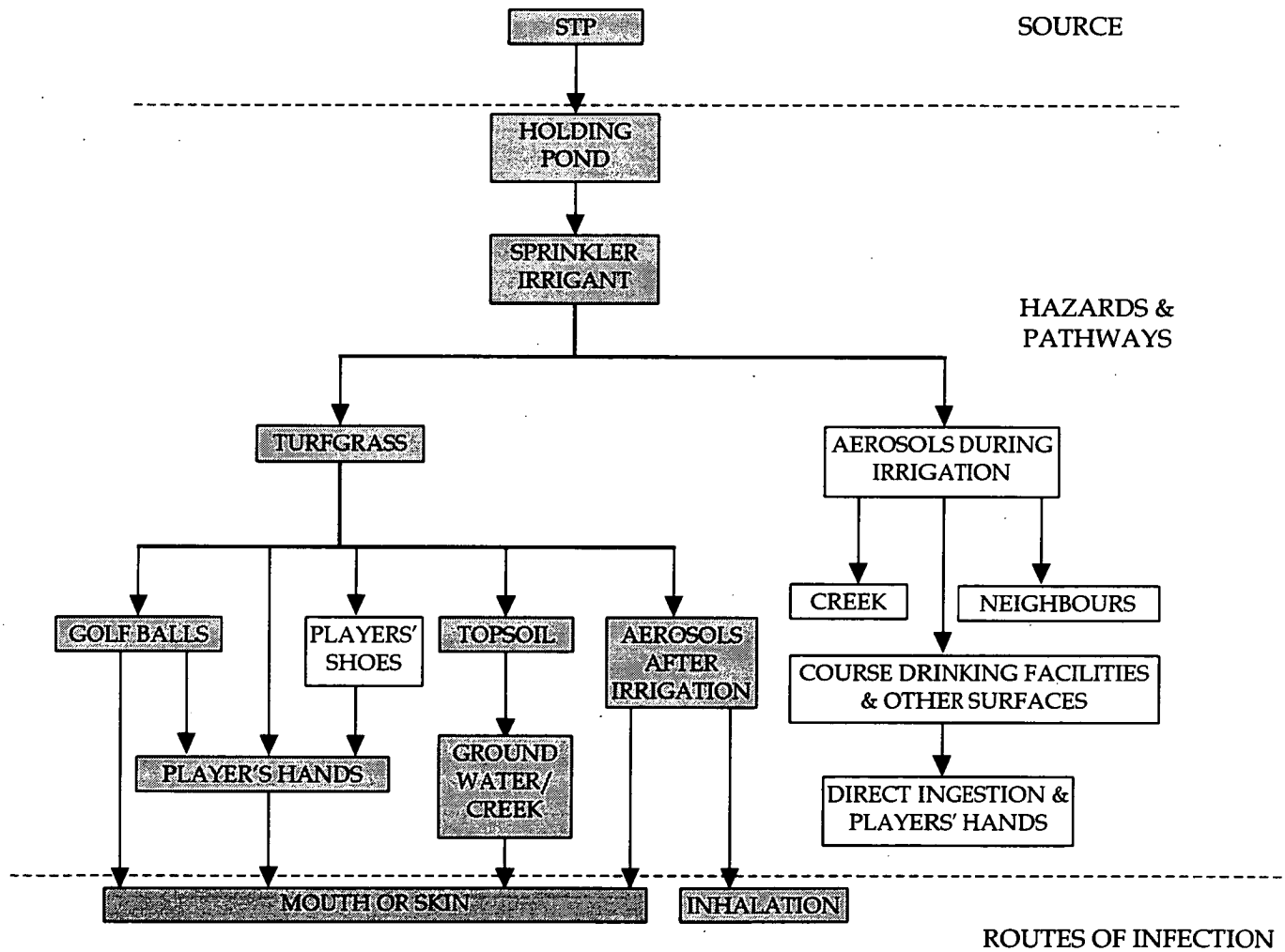


FIGURE 5.1 - Potential hazards and pathways of pathogen infection throughout a golf course (only the shaded pathways were monitored in this study).

5.4 Description of the Riverside Golf Course Reuse Scheme

The Riverside Golf Club operates an 18 hole golf course on 44.8 ha of land situated near the Tamar River, Launceston, Tasmania. Effluent is periodically pumped from the West Tamar Council's Riverside sewage treatment plant (STP) to irrigate the golf course. The STP is located 300 m away from the golf course (Figure 5.2 & Plates 5.1-5.3) which treats domestic sewage from a population of about 8 000 people to a secondary level with chlorination. Average daily throughput is 1.33 ML (Wright R., 1994).

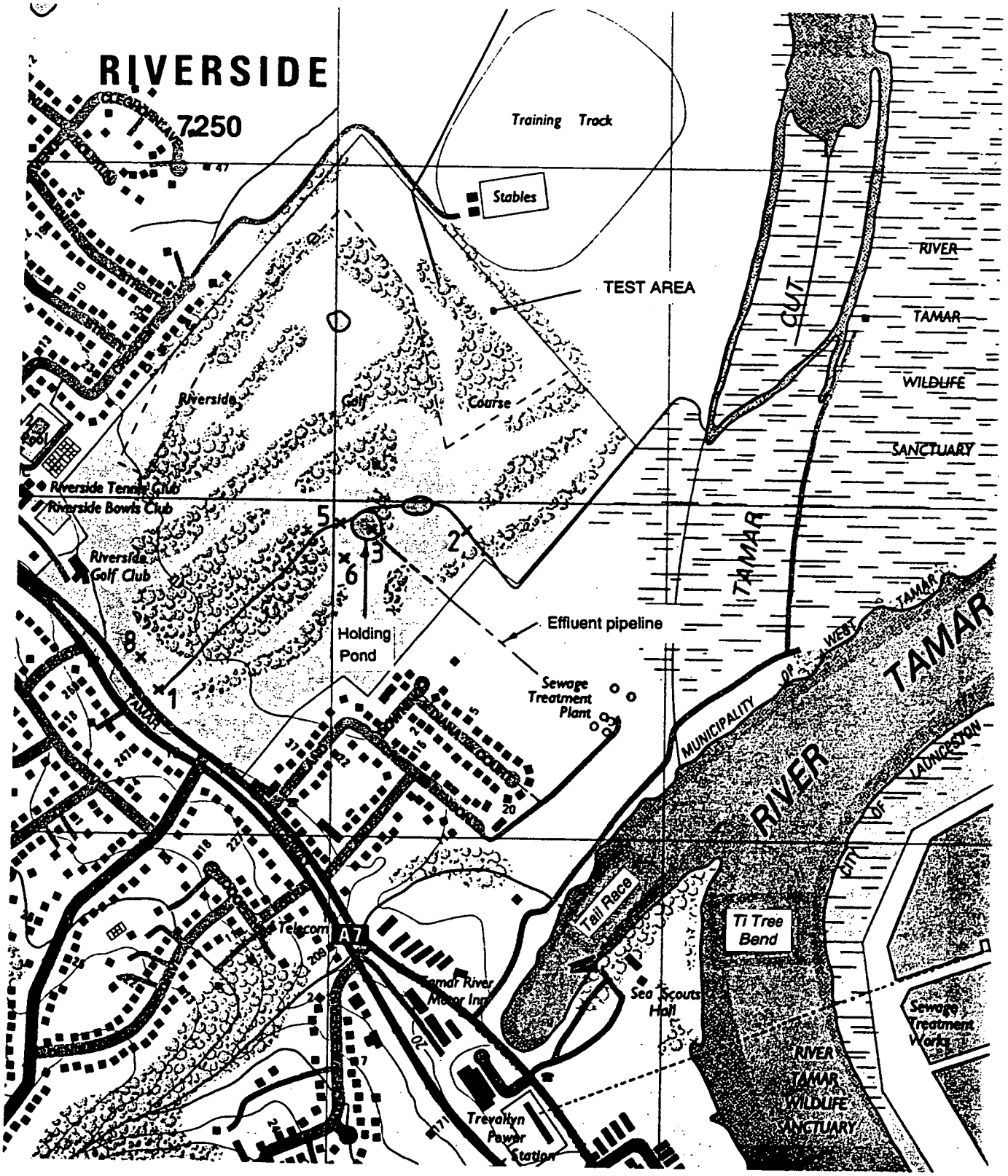
Some of this effluent is pumped into a 1 ML open holding pond located on the golf course during the irrigation season (usually October through to April) on an 'as required' basis (Plate 5.4). A separate pump draws water from this pond for distribution to a fixed sprinkler system around the golf course during the night. The pond stores the effluent for half a day before it is used. This system supplies approximately 38 mm of effluent per week to greens and tees and 25 mm per week to the fairways (Wright R., 1994). A backup system also can draw an alternative water supply from the Tamar River tail race of a small hydroelectric plant located nearby.

Irrigation first commenced at the golf course in the period of February to April, 1994. Effluent quality and soil samples were analysed after this period by the Tasmanian Department of Primary Industries and Fisheries, Launceston. The results indicated low levels of faecal coliforms in the effluent. Notably, faecal coliform levels were found to rise in the holding pond. The scheme to date complies with DELM (1994) *Guidelines for Re-use of Wastewater in Tasmania* and the conditions of the Directors of Environment and Public Health. Nevertheless, the microbiological data was based on the faecal bacteria levels in the STP effluent and not that found elsewhere on the golf course, particularly in the holding pond.

The irrigation system consists of two main types of pop-up sprinklers (Figure 6.1 & Plate 5.5-5.6). The large Toro 674 series is used for the fairways and are placed along the centre of the fairways spaced approximately 21 m apart. The fairways are defined by the boundary of mown turfgrass. These sprinklers could project a spray 26 m according to the manufacturers literature for the pump flow rates used. Although anecdotal evidence from the course superintendent suggests a throw of 20 m. The sprinklers could project spray well into the rough that skirted the fairways and there

FIGURE 5.2 - Locality map

(Illustrates the relative positions of Riverside Golf Course, the Riverside Sewage Treatment Plant and Ti Tree Bend. Preliminary study sample positions are also marked.)



Source: Department of Environment and Land Management (TAS), 1993, Tasmania Towns Street Atlas, 3rd ed.

Grid interval 500 m
× Sample site

was irrigation overlap between the sprinklers. The second type of sprinkler used are the typically smaller Hunter I30 or I31 models used for the tees and greens and could project a spray 14 m. They are spaced around the edges of the greens and usually in the middle of the tees. Each green has 4 to 6 sprinklers depending on the size of the green. A fair degree of irrigation overlap occurred. Plate 5.7 shows the comparison in the 'lushness' of the grass between the effluent irrigated area and the non-irrigated rough. The photograph was taken on the 28/3/95.

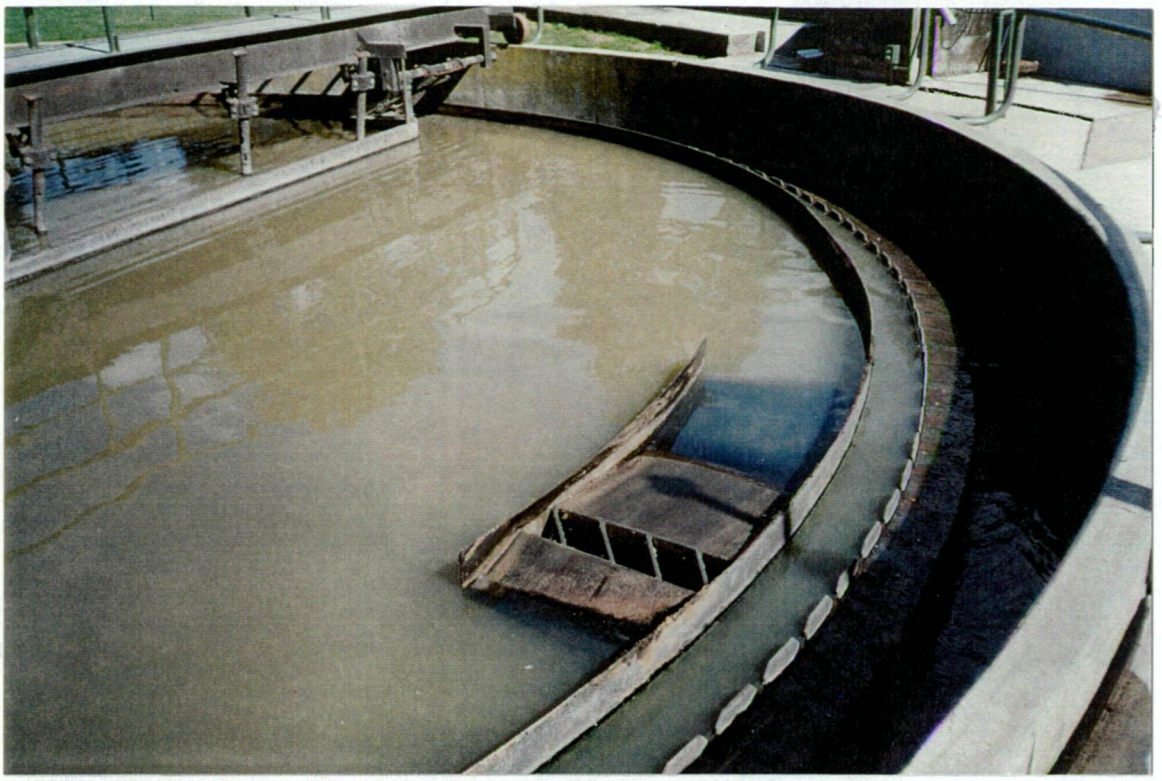


PLATE 5.1 - Riverside Sewage Treatment Plant - Primary settling tank

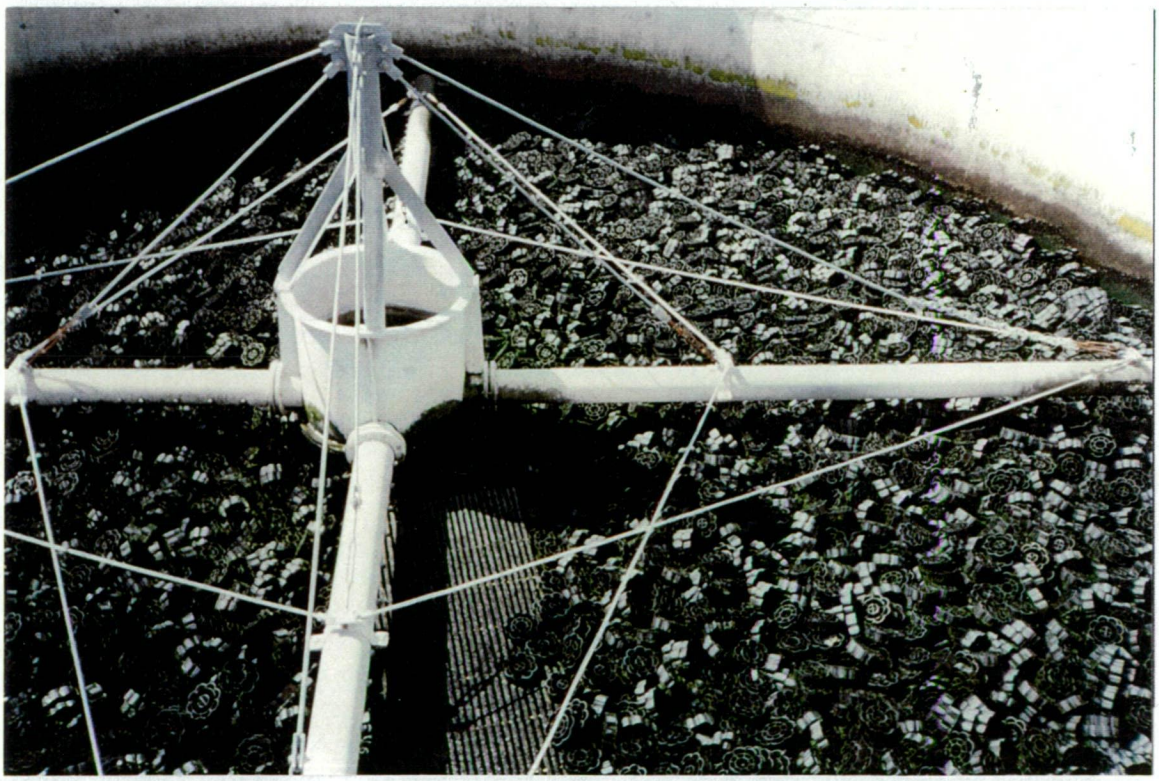


PLATE 5.2 - Riverside Sewage Treatment Plant - Trickling filter

PLATE 5.3 - Riverside Sewage Treatment Plant - Chlorine contact tank and golf course effluent draw-off pump (right foreground)

PLATE 5.4 - Golf course holding pond and effluent discharge from STP (background)

PLATE 5.5 - Toro 674 series fairway sprinkler

PLATE 5.6 - Hunter I30/I31 tees and greens sprinklers

PLATE 5.7 - Comparison between irrigated fairway and the rough

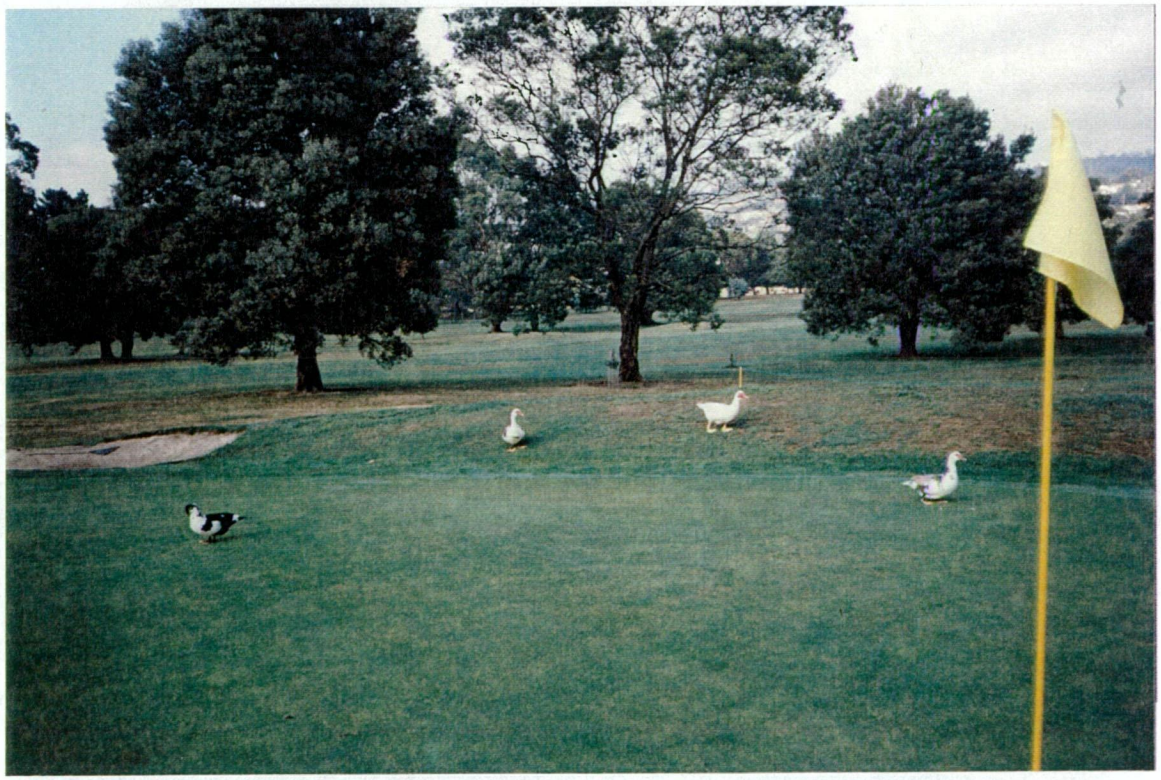


PLATE 5.8 - Water fowl that inhabit the golf course and holding pond

CHAPTER 6

MATERIALS AND METHODS

6.1 Introduction

In order to monitor the distribution of FC/*E. coli* throughout the golf course, three rounds of environmental sampling were undertaken during the 1995/96 irrigation season. Each round was conducted over a three day visit to the golf course. A test area (Figure 6.1) was selected in consultation with golf course staff within which sampling was to be conducted. The first five holes of the 18 hole course defined the test area.

Day 1 of each round involved setting up the sample site location markers and placing irrigant collectors at each site before nightfall. During the first night no irrigation took place in the test area. Day 2 involved collecting the control samples and filling the holding pond with effluent from the STP as done under normal operational conditions. The pond volume was increased by 50 to 100% of the original volume depending on the initial level of the holding pond. During the second night the test area was irrigated with effluent over an 8 hour period, 16 minutes for each green and 15 minutes per sprinkler on the fairways. Effluent-affected sampling was then conducted on the following day, Day 3, of the visit. The same pattern of environmental sampling was used for both control and effluent-affected sampling.

6.2 Microbiological Sampling Method

6.2.1 Microbiological Sample Collection

The following environmental samples were collected in the test area:

- irrigant water (Sample code TC or TT);
- fairway and green turfgrass (GC or GT);
- topsoil (SC or ST);
- swabs of players' hands (P#C or P#T) before and after they played through the test area;
- water used to rinse their golf balls (B#C or B#T) after they played through the test area;
- aerosols measured at head height (A#C or A#T); and

- water from a creek that passed through the test area (CC & CT)

where the first letter in the sample code refers to the type of sample (e.g. T = irrigant water sample) and the second or third letter in the sample code are defined as follows: C = control, T = effluent-affected, and # = M (morning), O (midday), or A (afternoon).

In addition, water samples of the STP effluent (STP) and water samples of the holding pond (HP) were also collected. The number and volumes of samples collected are listed in Table 6.1. Detailed sampling methodologies for each round are included in Appendix 1 and sampling site locations are indicated on Figure 6.1.

6.2.1.1 Water

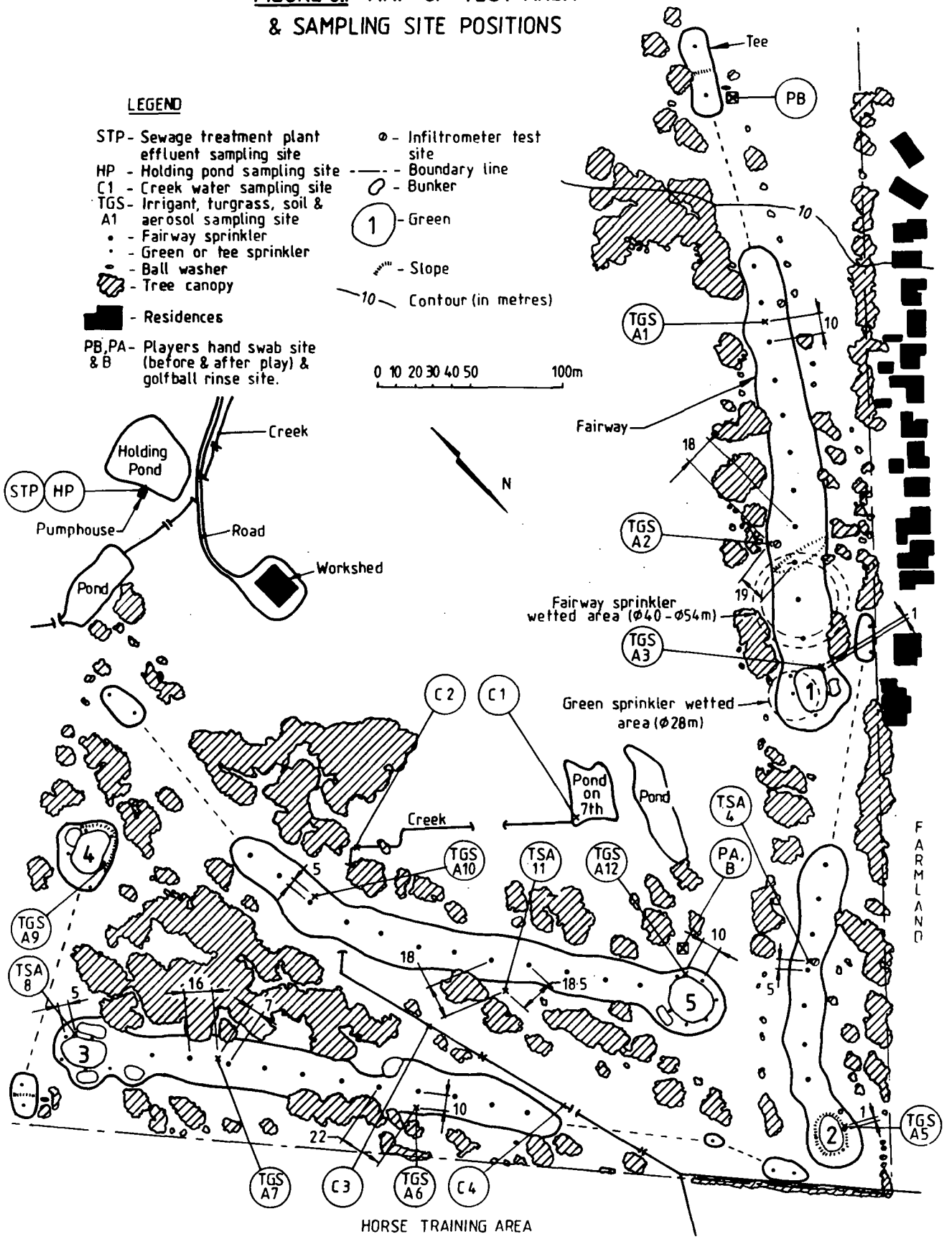
STP, HP, creek and irrigant samples were collected aseptically into containers which included 10% sodium thiosulfate and 15% disodium EDTA. The method of collection is described as follows:

- Riverside STP samples were collected into sterile bottles from the effluent as it discharged into the receiving pond for each round;
- Holding pond water samples were collected into sterile bottles directly from the pond for Round 1 and were collected from the pump housing as it was being pumped out of the pond to the irrigation lines for Rounds 2 & 3;
- Irrigation (irrigant) water was collected overnight by placing sterile containers on the turfgrass which trapped the effluent as it was being sprayed onto the golf course. Rainwater provided control samples;
- Ambient creek water (when present) was collected into sterile bottles.

6.2.1.2 Turfgrass

For Round 1, turfgrass samples were not collected as it was originally thought that most of the bacteria would percolate into the root zone and topsoil. This was subsequently found not to be the case. Therefore, in subsequent rounds samples of the actual turfgrass were taken.

FIGURE 6.1 - MAP OF TEST AREA & SAMPLING SITE POSITIONS



	Round 1			Rounds 2 & 3		
Sample Type	*Number and when collected per round*	*Total*	*Amount of Sample*	*Number and when collected per round*	*Total*	*Amount of Sample*
STP	Double sample taken during filling of the holding pond	2	250 mL	Double sample taken during filling of the holding pond	2	250 mL
HP	Taken before and after irrigation	2	250 mL	Taken overnight during irrigation	3	250 mL
C	4 control and 4 effluent-affected taken late afternoon	8	< 250 mL	4 control and 4 effluent-affected taken late afternoon (when present)	8	< 250 mL
T	12 control and 12 effluent-affected taken at daybreak	24	50–250 mL	9 control and 9 effluent-affected taken at daybreak	18	50–250 mL
G	0	0	0	9 control and 9 effluent-affected taken at daybreak	18	3 cm deep x 10.5 cm diameter
S	12 control and 12 effluent-affected taken at daybreak	24	5 cm deep x 2 cm diameter	9 control and 9 effluent-affected taken at daybreak	18	5 cm deep x 2 cm diameter
B	2 players morning, midday and afternoon on Day 2 and Day 3 after play	12	150 mL	4 players morning, midday and afternoon on Day 2 and Day 3 after play	24	150 mL
P	2 players morning, midday and afternoon on Day 2 and Day 3 before and after play	24	15 mL	4 players morning, midday and afternoon on Day 2 and Day 3 before and after play	48	15 mL
A	12 samples morning, midday and afternoon on Day 2 and Day 3	72	160 L	9 samples morning, midday and afternoon on Day 2 and Day 3	54	160 L

Day 2 = Control sampling (before irrigation),
Day 3 = Effluent-affected sampling (after irrigation)

TABLE 6.1 - Sample collection table

For Rounds 2 & 3, nine cores of turfgrass were collected per day. In consultation of the course staff, the 'holer' (that is used to cut the holes in the greens) was sterilised with methanol and then used to cut a 10.5 cm diameter rim around the turfgrass (Plate 6.1). A presterilised knife was used to lift the upper 5–6 cm profile from the underlying soil. The layer of turf grass (~3 cm thick) was separated aseptically from the attached soil and rootlets by means of a knife (Plate 6.2). (For the green samples, turfgrass was taken from beside the green and not from the green itself.)

For Round 2, the cylindrical 10.5 cm diameter x 3 cm deep core was then placed into a chilled esky and taken back to the microbiological laboratory for analysis in Hobart.

Preparation for membrane filtration in the laboratory involved cutting a 10 gram wedge from the core which was then mixed with 90 mL of 0.1% peptone, pH 7.2, for 30 seconds in a stomacher bag using a stomacher machine. From the supernatant, 10 mL and 1 mL samples were taken and filtered using the membrane filtration method for bacterial analysis. Small quartzite pebbles in the green turfgrass samples caused breakage of the stomacher bags making mixing difficult.

The turfgrass FC/*E. coli* results from sampling Round 2 showed essentially no detection of organisms at a minimum detection level of 10 cfu/gram of turfgrass. The actual loading of organisms deposited per area of turfgrass was estimated between 4.2-6.6 cfu/cm^2 based on an FC/*E. coli* count of 1 000 cfu/100 mL in the effluent coming from the holding pond (see Appendix 8). The average turfgrass weight to surface area ratio for the greens and fairways was estimated at 2.00-1.32 g/cm^2 respectively, so a 10 gram sample corresponds to a 5 cm^2 sample for the greens and a 7.6 cm^2 sample for the fairways. Expected FC/*E. coli* counts for these samples would then be in the range of 21-76 cfu/10 g of turfgrass. Only 1 gram was effectively filtered, meaning detection was quite limited.

To enhance detection of turfgrass FC/*E. coli,* the method of sampling turfgrass was revised for Round 3 as follows: the same 10.5 cm diameter x 3 cm deep turfgrass core was removed from the ground and then it was placed in a stomacher bag containing 150 mL of 0.1% peptone water, pH 7.2, and gently hand-massaged for 1 minute (Plate 6.3). The core was squeezed to retrieve as much supernatant as possible, then aseptically removed from the rinse water and replaced back from where it was removed. The supernatant was poured into a bunzl jar with Na EDTA and Na thiosulfate. The jar was sealed and labeled and then placed into a cool box at 4-10°C.

Four samples of turfgrass (2 green and 2 fairway samples) were retained to be weighed and measured for the calculation of the area to weight ratio of the turfgrass.

6.2.1.3 Soils

During the first day of the Round 1, infiltrometers were placed at various positions (Figure 6.1) around the test area to determine the infiltration rates of water into the various soils in order to help determine how deep a soil sample should be taken. This equipment essentially consisted of a 75 mm diameter plastic tube 1 meter high filled with water. The rate of drop in the water level indicates how quickly the water moved

through the soil column. Results indicated that the first 5 cm of topsoil was sufficient to ensure that all the soil horizon affected by the effluent was collected. The soil typically had a high clay content of 20–40%.[1]

For Round 1, twelve composite soil samples were collected from places of exposed soil in the evening of Day 2 and early in the morning of Day 3 (after irrigation) at the designated 12 sites. For Rounds 2 and 3, nine samples were collected early in the morning before and after irrigation at 9 designated sites when the turfgrass samples were collected. Three 5 cm deep samples were taken at each site using a modified sterile 25 mL syringe barrel of 20 mm in diameter from soil that was exposed after the turfgrass core was removed (Plate 6.4). The samples were composited in a sterile bunzl jar and placed in an esky.

6.2.1.4 Swabs of Players' Hands

For Round 1, hand swabs from two players were taken morning, midday and afternoon for each day. Each player was swabbed twice: once as a control, before teeing off at the first hole, and once again after play at the 5th green (Plate 6.6). For Rounds 2 & 3, four, instead of two, players were sampled each time. At the start of play, golfers' hands were washed in warm soapy water and then thoroughly rinsed. The palm and fingers of the players' hands were rubbed all over with a cotton tip swab which had been dipped into 15 mL of 0.1% peptone water, pH 7.2, with Tween 80. For both hands the same area of each hand (150 cm^2) was swabbed 5 times to achieve maximum recovery. Only one hand (300 cm^2) was swabbed if the player wore a glove. After sampling, the swab was aseptically discharged into peptone water. This procedure was repeated after play at the 5th green.

6.2.1.5 Golf balls

Ball rinse samples of the golf balls were taken morning, midday and afternoon for each day only at the end of play at the 5th green at the same time the players' hands were swabbed (Plate 6.5). Two balls were rinsed for Round 1 and four balls were rinsed for Rounds 2 & 3. Hand swabs corresponded with the golf ball rinses for each player.

Players were provided with a new sterilised golf ball at the beginning of the test area just before each aerosol sampling run. After playing the five holes the golf balls were immersed in 150 mL of 0.1% peptone water, pH 7.2, with Tween 80, in a bunzl jar and

[1] The higher the clay content the slower the infiltration rate.

rinsed by swirling for 30 s. The golf ball was then aseptically removed and returned to the player.

6.2.1.6 Air

Twelve samples of aerosols were collected morning, midday and afternoon, each day, for Round 1 and 3 x 9 samples were collected each day for Rounds 2 & 3. Aerosol samples were collected using a Biotest RCS Centrifugal Air Sampler (Plate 6.7). Air was sampled for 4 minutes which corresponds to a 160 L air sample. Aerosols in the sample impinge onto strips containing MacConkey agar (Gelman Agar Strip C).

All samples were stored at <5°C, except for biotest air strips which were stored at ambient temperature (10–20°C).

Na EDTA and Na thiosulfate were added to the water samples in order to prevent any heavy metals or residual chlorine used by the sewage treatment plant from killing or sublethally injuring any bacteria collected. Peptone water and Tween 80 were used to resuscitate and transport viable organisms.

PLATE 6.3 - Peptone water being added to the turfgrass sample. Both are mixed together and supernatant is drawn off as the sample.

PLATE 6.4 - 5 cm soil cores taken from exposed soil with a sterile open syringe

PLATE 6.1 - Collecting turfgrass samples using a presterilised green 'holer'. White container (foreground) collected the irrigant.

PLATE 6.2 - Removing upper layer of turfgrass with presterilised knife and taking measurements of soil temperature and light intensity

PLATE 6.5 - Golf ball rinsed at 5th green and return to player with the means of a presterilised pair of scissors

PLATE 6.6 - Taking a swab of a player's hand at the 5th green

PLATE 6.7 - Biotest RCS Centrifugal Air Sampler taking an aerosol sample at headheight

PLATE 6.8 - Wind speed, wind direction and light readings being taken during aerosol sampling

6.2.2 Microbiological Sampling Strategy

Samples of irrigant water, turfgrass and soil were taken from the test area each day in the early morning in order to measure the levels of FC/*E. coli* just before play started when players would be at most risk of coming into contact with any pathogens. Aerosols were also sampled three times each day for each site when the players were on the course and at risk of inhaling pathogens in aerosol. This was done in conjunction with taking swabs of players' hands and golf ball rinse samples. Taking these samples three times a day was intended to provide an indication of the rate of faecal bacteria reduction throughout the day. Holding pond samples collected for Rounds 2 and 3 served to monitor the FC/*E. coli* levels in the holding pond effluent during irrigation. Four creek water samples were collected per day in the late afternoon in order to monitor background levels of faecal contamination.

In practice it became necessary to make improvements from round to round when it was discovered certain environmental samples needed more thorough and sensitive sampling. The changes and the reasons for change in sampling methodology between rounds are argued below.

6.2.2.1.1 Reasons for Amendments in Sampling Methodology for Round 2

Due to the very little presence of FC/*E. coli* counts found in the soil for Round 1 compared with the high counts found in the irrigant water, it was realised that, either the FC/*E. coli* dieoff was very rapid or very little effluent reached the soil column and remained in the turfgrass (Result Tables 1.1 & 2.1). In addition, very little FC/*E. coli* was found on golf balls, players' hands or in the air the day following irrigation of the effluent (Result Tables 3.1 & 4.1).

From these results it became clear that the turfgrass also needed to be sampled for the purposes of ascertaining the fate of FC/*E. coli*. With the decision to collect turfgrass samples, the number of sample sites for irrigant water, soils and aerosol collection were reduced from 12 to 9 due to budget constraints. Efforts were made to retain a high degree in variability between the sites. That is, retaining a variation in the type of turfgrass sampled and a variation in the distances and positions the sites were located relative to the nearest sprinklers.

Therefore, 9 control and 9 effluent-affected samples were subsequently collected for irrigant water, turfgrass and soil samples and 3 x 9 control and effluent-affected

samples for aerosols. Sampling points to be retained were sites 1, 2, 3, 5, 6, 7, 9, 10 and 12. In addition, to achieve greater detection of faecal bacteria potentially contaminating the players' hands, the number of players' hands and golf balls sampled each time was increased from 2 to 4.

6.2.2.1.2 Reasons for Amendments in Sampling Methodology for Round 3

The advantages of changing the turfgrass sampling methodology from Round 2 to 3 were twofold; a larger sample enhances the minimum level of detection, and the recovery of viable organisms directly into peptone water avoids possible dieoff by desiccation during transport to the laboratory.

6.2.3 Microbiological Sample Analysis

All samples were analysed in a NATA registered laboratory (Aquahealth, University of Tasmania, Hobart) using the membrane filtration method (American Public Health Association et al. 1992).

All water samples were analysed within 24 h of collection. Samples of STP effluent, holding pond water, irrigation water, turfgrass supernatant, ambient creek water, rainwater, hand swab rinse water and golf ball rinse water were filtered using a 0.45 µm membrane filter (Gelman). In the case of soil, a 10% suspension was prepared (10 g into 90 mL 0.1% peptone water, pH 7.2), allowed to settle for 2 minutes and then the supernatant was membrane filtered using a 0.45 µm membrane filter. The volume of water which was filtered varied between 0.1 mL and 100 mL depending on the particulate content and the expected level of contamination. The filters were placed on membrane lauryl sulfate agar plates and incubated at 30°C for 2–4 h, then at 44°C for 14–18 h. Presumptive faecal coliforms (yellow colonies) were counted and subcultured into lauryl tryptose broth and confirmed as faecal coliforms if they produced gas at 44°C after 24 h.

E. coli was confirmed as indole positive faecal coliforms in tryptone water after 24 h at 44°C.

The Biotest airstrips (Mackonkey agar) were incubated at 37°C for 48 h. Presumptive faecal coliforms (pink colonies) were counted, subcultured into lauryl tryptose broth and confirmed as above.

Faecal coliform/*E. coli* counts were expressed per 100 mL for water samples, per 100 cm^2 for turfgrass {or per 100 mL equivalent (eq.), that is, the surface area that would receive 100 mL of irrigant}, per g for soils, per 100 cm^2 for players' hands, per 50 cm^2 for golf balls and per m^3 for air. Appendix 9 provides an explanation of the cfu/100 mL eq units for turfgrass FC concentration and how they were calculated.

It was hoped for the Round 3 turfgrass samples, a 100 mL of turfgrass eluent could be filtered thus enhance detection to 1 cfu/mL eq. Unfortunately, due to the amount of particulate matter, 10 mL samples were the largest that could be filtered giving a detection limit of 10 cfu/100 mL.

Due to the problem of breaking stomacher bags in the preparation of soil samples for analysis, Round 2 and 3 samples were vortex mixed instead after the clods of soils were broken up by hand.

6.3 Meteorological, Physico-Chemical Sampling Methods

6.3.1 Meteorological, and Physico-Chemical Sample Collection and Analysis

6.3.3.1 Weather Conditions

Weather forecasts were used to judge similarity between the weather patterns over the two days before each sampling round was commenced. Weather data were obtained from the Bureau of Meteorology recorded at Ti Tree Bend (Figure 5.2). Bright sunshine hours, obtained also from the Bureau, were measured at Launceston Airport (Appendix 3).

6.3.3.2 Wind Characteristics

Wind speed and direction were measured during aerosol sampling using an Airflow LCA6000 rotary vane anemometer, compass and wind flag.

6.3.3.3 Light Intensity

Light intensity related to UV irradiation was measured during the collection of turfgrass sampling and aerosol sampling using an Emtek LX-101 lux meter.

6.3.3.4 Air Properties

Air temperature and humidity were measured for each sample during the collection of turfgrass samples and during the collection of the aerosol samples using a psychrometer.

6.3.3.5 Water Properties

For each water sample conductivity (K), pH, and temperature were measured. Measurements were taken using WTW pH and conductivity meters. In regard to the irrigant water samples, pH and conductivity were not be measured in the field in order to avoid externally contaminating the samples. Instead they were measured in the laboratory after microbial analysis using the samples that had Na EDTA and Na thiosulfate in them. These two chemicals will affect conductivity and pH readings. Therefore a linear regression for conductivity was calculated based on paired like water samples, one with and the other without these chemicals (Appendix 5). From this regression the true conductivity was estimated for the irrigant waters and reported in the Results Tables. pH was not adjusted since only a variation of 0.1 pH was revealed by the available data. Turbidity was measured for the Holding Pond water for Rounds 2 and 3 using a Hach DR/2000 Spectrophotometer.

6.3.3.6 Soil Properties

Soil temperature was measured for each soil sample during soil sample collection using the temperature probe of a WTW pH meter (Plate 6.2). The probe was inserted 2 centimetres into the soil. Soil conductivity and pH measurements were taken in the laboratory by mixing 20 g of soil with 100 mL of distilled water, that is a 1:5 ratio, mixing end over end for two minutes per sample and measuring with the WTW pH and conductivity meters.

Soil moisture measurements were made on a dry weight basis (Doyle 1995: 42). Soil samples were weighed in aluminium petri dishes then oven dried for 24 hours at 104–5°C. Dry samples were reweighed. The difference in weight divided by the dry weight and multiplied by 100 gave per cent soil moisture.

6.3.2 Meteorological and Physico-Chemical Sampling Strategy

Light intensity, air temperature, humidity and wind speed were measured for the purposes for correlating desiccation and UV destruction of air-exposed FC/*E. coli* with these parameters (Plate 6.2). Wind speed and direction were also monitored for identifying any patterns of aerosol movement in the test area (Plate 6.8).

Water and soil conductivity, pH and temperature, and soil moisture were monitored for conditions that affect FC/*E. coli* and pathogen survival in these media.

CHAPTER 7

RESULTS

Firstly, preliminary data obtained before the case study will be presented and secondly, the results of the case study will be presented involving an inter-round comparison of results followed by examining the results of each sampling round in turn. Tabulated results are located at the end of this chapter on page 201 and following.

7.1 Preliminary Study

Limited microbiological testing of STP effluent and HP water, air and players' hands was undertaken in June 1995 and other data were obtained from West Tamar Council (Appendix 2). This information provided a guide in the design of the sampling methodology. Eleven STP effluent samples were taken before the irrigation season and had counts of *E. coli* in the range of <10–600 cfu/100 mL. Four holding pond samples had *E. coli* counts of 90, 500, 100 and 1 300 cfu/100 mL. Notably, *E. coli* concentrations increased in the holding pond compared with the STP sample taken the same day.

7.2 Environmental Comparisons Between Sampling Rounds

7.2.1 Weather Conditions

Monthly average temperatures throughout the irrigation season, from October 1995 through to March 1996, were below the long term average for both daily maximum and minimum temperatures (Bureau of Meteorology, TAS, *Monthly Weather Review*, Oct-Mar). The average daily maxima for the 6 months was 21°C with a range between 14–29°C. Overnight minimum temperatures ranged between 1–17°C (Appendix 3). Rainfall totaled 381.8 mm over 159 days. The month of January, 1996, recorded the highest on record. Monthly totals were 55.8, 34.2, 58.6, 139.4, 50.6 and 43.2 mm from October through to March. The last four figures were above the long term average. In spite of the high occurrence of inclement weather, an average of 8.3 h/d of bright sunshine was recorded, compared with the long term average of 8.4 h/d (Bureau of Meteorology, TAS, *Monthly Weather Review*).

Table 7.1 presents the average weather conditions over the two sampling days providing a comparison of the weather conditions between sampling rounds.

Sampling Round	*Maximum average temperature, °C*	*Minimum average temperature °C*	*Average daily rainfall, mm*	*Average bright sunshine hours*
1	16.0	5.5	1.8	8.6
2	19.5	8.5	0.8	4.3
3	24.0	10.5	1.0	6.4

TABLE 7.1 - Average weather conditions for each sampling round

Conditions are similar from Round 1 to Round 3 with the exception of gradual increases in temperatures.

7.2.2 Vegetation Types

Turfgrass varieties employed on the course are fine Bent grass for the greens and a mixture of Creeping Fescue, Chewing Fescue and different varieties of Rye for the fairways. The tees are a mix of course Bent, Fescue and Rye grass.

7.2.3 Soil Types

Soils type for the fairways tended to be a dark clay loam (approximately 20–40% clay) with a high organic content. The greens had a similar soil structure with the inclusion of coarse quartz sand used to enhance permeability. Soil description for each site slightly varies between each round (Table 7.2).

	Round 2	*Round 3*
Site 1	Medium brown fine clay loam with rootlets	Medium brown fine clay loam with granular peds
Site 2	Medium brown/grey fine loam	Light brown fine loam with granular peds
Site 3	Dark brown/grey with course sand fragments	Dark brown granular peds with course sand fragments
Site 5	Light brown soil with coarse sand	Dark brown granular peds with course sand fragments
Site 6	Dark brown/grey fine loam sand with rootlets	Reddish brown fine loam
Site 7	Dark fine clay loam with high organic content with orange tinge and fine rootlets	Dark fine organic clay loam with granular peds
Site 9	Lumpy medium grey brown loam with coarse sand	Dark brown granular peds with course sand fragments
Site 10	Dark brown clay loam with orange tinge and fine rootlets	Reddish brown fine loam
Site 12	Medium grey-brown soil with clumps of rootlets and coarse sand	Dark brown granular peds with course sand fragments

TABLE 7.2 - Soil characteristics for each site

7.2.4 Irrigation Schedule and Rainfall

Appendix 6 displays the irrigation schedule conducted in the test area throughout the irrigation season. The duration of irrigation is graphed for each fairway or the five greens in minutes for the previous night. As a comparison, rainfall is also graphed, although in different units (mm). The irrigation season started on the 4/10/1995 and finished on the 27/3/1996.

From the irrigation schedule and actual irrigant levels found in the irrigant collectors it was calculated that the fairway sprinklers irrigate at a rate of approximately 190 L/min/sprinkler over a 40 m diameter wetted area for 2.4 min/d on an average and the green sprinklers irrigate at a rate of approximately 80 L/min/sprinkler over a 28 m diameter wetted area for 10.6 min/d on an average. Taking into account the overlap between sprinklers (2 for fairways and 3 on average for the greens) this equates to approximately 5 mm of effluent applied per week for the fairways and 29 mm for the greens compared with the typical operating conditions of 25 and 38 mm respectively. Lower applications for this season are indicative of the unusually high rainfalls occurring over the period.

7.3 Microbiological Comparisons Between Sampling Rounds

7.3.1 STP Effluent

Six samples of STP effluent recorded counts between <1–7 600 FC/100 mL and between <1–1 900 *E. coli*/100 mL counts (Result Tables 1.1–1.3, where the mean = 14 cfu/100 mL, 95% range = 0–8 460 cfu/100 mL).

7.3.2 Holding Pond

Eight samples taken during the irrigation season recorded FC/*E. coli* counts between 800–10 300 cfu/100 mL.

7.3.3 Irrigant

FC/*E. coli* counts in the effluent-affected irrigant samples reflected the counts in the holding pond samples (Result Tables 2.1–2.3). The geometric means for Round 1, Round 2, and Round 3 are 1 800, 475, 1 130 cfu/100 mL, respectively.

It was found that for all rounds combined, the FC/*E. coli* counts in the holding pond ($\bar{x}$ = 1 840 cfu/100 mL, 95% range = 372–9 120 cfu/100 mL) were considerably higher than the counts in the irrigant samples ($\bar{x}$ = 945 cfu/100 mL, 95% range = 187–4 760

cfu/100 mL). A t-test statistical analysis that compared all holding pond sample results with all irrigant sample results, $t_{1,32} = 2.038$, $P = 0.0583$, gave a borderline result for a 95% confidence interval that there is a significant difference between the two. With this test, the inter-round difference between levels in the holding pond were not taken into account. If they were then the difference between the means may well be significant.

7.3.4 Soils

For the soil samples, only a few Round 1 sites gave detectable amounts of FC/*E. coli* for both control and effluent-affected samples. For Round 2, no detectable counts of FC/*E. coli* for controls or effluent affected samples were recorded for all sites. Whereas, several sites in Round 3 had detectable faecal coliform samples. Notably, site 10 recorded three positive samples for all rounds and sites 3 and 7 recorded two.

The difference in soil moisture was insignificant before and after irrigation for all rounds, $t_{1,52} = -0.304$, $P = 0.382$, {control mean = 61.1%, effluent-affected mean 62.1% (Appendix 7)}. Soil moisture also significantly decreased over the irrigation season despite the heavy rainfalls in January, {Round 1 and 2 control comparison, $t_{1,16} = 2.49$, $P = 0.0188$, and Round 2 and 3 control comparison, $t_{1,16} = 2.23$, $P = 0.028$, Round 1 mean = 76.3%, Round 2 mean = 63.7% and Round 3 mean = 43.4% (Appendix 7)}. Soil temperatures varied between 8.2–17.7°C. Soil temperature appears to fluctuate with the rise and fall of the ambient air temperature although lagging behind due to its high thermal capacitance.

7.3.5 Golf balls, Players' Hands and Aerosols

Extremely few and very low counts were detected for all rounds for each of these sample types collected (Result Tables 3.1–4.3).

7.4 Round One Microbiological Results (11-12th Oct, 1995)

Weather conditions for Day 2 were fine with some cloud. The maximum and the previous night's minimum temperatures were 17.0°C and 7.0°C respectively. Previous 24 h rainfall to 9 a.m. of 3.6 mm and bright sunshine hours of 11.7 h were recorded. For Day 3, the maxima and overnight minima were 15.0°C and 2.0°C respectively. No rainfall for the previous 24 h to 9 a.m. and 5.4 bright sunshine hours were recorded. This day was cooler and more overcast than Day 2.

Only two irrigation events on the greens had occurred since the beginning of the season, some seven days before the sampling round which was then followed by 15.8 mm of rain.

7.4.1 STP, Holding Pond and Creek Water (Result Table 1.1)

The two samples taken of the sewage treatment plant (STP) effluent resulted in relatively low counts of <1 and 230 cfu/100 mL for FC/*E. coli*. The holding pond microbial counts were somewhat higher. Before and after irrigation, samples had counts of 10 300 cfu/100 mL and 1 900 cfu/100 mL respectively. Very low levels of FC/*E. coli* sampled from the creek indicated almost no trace of faecal matter in the creek before and after irrigation.

7.4.2 Irrigant (Result Table 2.1)

Irrigant sample FC/*E. coli* counts typically correlated with the FC/*E. coli* counts in the holding pond. For the fairways, counts varied between 1 200–3 100 cfu/100 mL. No counts were recorded for the green sample sites 5, 8, 9 & 12, since irrigation of the greens did not take place despite the controllers being programmed to do so.

7.4.3 Soils

Very little FC/*E. coli* was found in the soil cores taken at depths between 0–5 cm deep below the soil surface (Result Table 2.1). Only two controls and two effluent-affected soil samples were positive for FC/*E. coli*. No appreciable difference can be ascertained before and after irrigation. Site 10 (control) & 7 (effluent affected) had counts equal to or above 100 cfu/g.

7.4.4 Golf Balls and Players' Hands (Result Table 3.1)

No detectable FC/*E. coli* made contact with the players via their golf balls or their hands. In particular, samples taken the morning directly after treatment bore no positive result. Therefore, there was no difference between the control samples and the effluent-affected samples.

7.4.5 Aerosols (Result Table 4.1)

In regard to microbial infection of players via inhalation, almost no detectable counts of FC/*E. coli* were found at head height at any site, morning, noon and afternoon, before and after irrigation. The only exception was 13 FC/m^3 at site 11 the morning after irrigation. Wind speed at this site during sampling was 0.5–1.5 m/s.

7.5 Round Two Microbiological Results (8-9th Nov, 1995)

Weather conditions over the two days were mainly fine and cloudy. For Day 2, maximum and minimum temperatures recorded were 19.0°C and 10.0°C respectively. Previous 24 h to 9 a.m. rainfall of 1.6 mm and bright sunshine hours of 3 h were recorded. Day 3 maxima and minima were 20.0°C and 7.0°C respectively. No rainfall was recorded for the previous 24 h and bright sunshine hours were 5.5 h. Therefore, weather conditions for both control and effluent-affected sampling days were similar.

The previous period's irrigation record up to Round 2 reveals several long durations of green irrigation, involving two 36 min applications, occurring two and three days previously. Fairways were irrigated for 10 min on two occasions 3 and 6 days previously. Rainfall over the previous week was 6.4 mm.

7.5.1 STP, Holding Pond and Creek Water (Result Table 1.2)

Reviewing the STP effluent FC/*E. coli* results, counts were very low, <1 cfu/100 mL for both samples. The holding pond effluent samples gave slightly lower readings than for Round 1 ranging between 800–1 000 cfu/100 mL and were fairly consistent. No creek samples were taken since the creek was dry giving an indication that the soil was drier during the first round.

7.5.2 Irrigant (Result Table 2.2)

The irrigant control samples gave counts of FC/*E. coli* <10 cfu/100 mL[2] except site 9 which had a count of 140 cfu/100 mL. The irrigant samples after irrigation resulted in FC/*E. coli* counts similar to, or slightly less than, the holding pond counts ranging between 150 cfu/100 mL at site 9 to 1 200 cfu/100 mL at site 3.

7.5.3 Turfgrass

Turfgrass control samples all gave a FC/*E. coli* result of <10/gram of grass (<1 400 cfu/100 cm² of fairway turfgrass or <2 000 cfu/100 cm² of green turfgrass) except for site 10 which gave 30 FC/*E. coli*/gm (4 000 cfu/100 cm²). The FC/*E. coli* counts for the effluent-affected samples also were <10 cfu/g except for site 9 which recorded 210 cfu/g (42 000 cfu/100 cm²).

When converting cfu/g to cfu/100 mL eq. of irrigant deposited, the accuracy of measurement is so poor, varying between <1 800–<8 500 cfu/100 mL eq. compared

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[2] Note: only a 10 mL dilution was used during membrane filtration.

with an actual effluent microbial quality of 800–1000 cfu/100 mL that came from the holding pond. No effective analysis can be conducted on these results.

7.5.4 Soils

The soils showed no signs of faecal contamination before or after irrigation at any site to the accuracy that was measured (<10 cfu/g of soil).

7.5.5 Golf Balls and Players' Hands (Result Table 3.2)

Despite increasing the sampling population from 2 to 4 players, little signs of faecal pollution were detected. On Day 2 nothing was detected for both golf ball and hand samples. On Day 3, after irrigation, the result was the same with the exception that 4 faecal cfu/50 cm^2 were detected from one golf ball in the afternoon.

7.5.6 Aerosols (Result Table 4.2).

Aerosol samples for both control and effluent-affected days gave consistent results of <7 cfu/m^3.

7.6 Round Three Microbiological Results (26-27th Mar, 1996)

Weather conditions (Appendix 3) for Day 2 were fine but cloudy with maximum and minimum temperatures of 25.0°C and 10.0°C respectively. No rainfall to 9 a.m. occurred, and hours of bright sunshine were 4.0 h. For Day 3 conditions were fine but overcast with the maxima and minima of 23.0°C and 11.0°C being recorded respectively. Rainfall to 9 a.m. was 2.0 mm and hours of bright sunshine were 8.7 h.

Irrigation for the previous few weeks had been the most intense for the season, particularly on the greens, with 3.0 mm of rainfall occurring over the previous week (22 mm of rain occurred 10 days previously).

7.6.1 STP, Holding Pond and Creek Water (Result Table 1.3)

The two STP effluent samples recorded FC counts of 20 and 7 600 cfu/100 mL and *E. coli* counts of 20 and 1 900 cfu/100 mL respectively. The holding pond effluent samples taken throughout irrigation gave counts of 1 900, 1 900 and 2 600 cfu/100 mL. Only one sample of creek water was taken for each day at the pond on the 7th hole since the creek was dry. Counts at this site were 520 and 1 500 cfu/100 mL for control and effluent-affected samples respectively.

7.6.2 Irrigant (Result Table 2.3)

No controls were collected since there was no overnight rain. After irrigation the FC/*E. coli* counts of the irrigant samples varied between 500–7 300 cfu/100 mL. All these counts were less than the holding pond counts except for site 3.

7.6.3 Turfgrass

With the revised method of sampling, detection sensitivity was increased sufficiently to provide useful results. Nevertheless, with direct rinsing of the turfgrass, the sensitivity of detecting all other naturally occurring bacteria that grew on lauryl sulfate agar likewise increased. They tended to crowd the plates making reading faecal bacteria colonies quite difficult at times. This necessitated some retesting the following day as indicated in the table of results.

Notably both control and effluent-affected samples had significant counts of FC/*E. coli*. The controls varied between <14–920 cfu/100 mL eq. and the effluent-affected sample results varied from 66–13 000 cfu/100 mL eq. Sites 1 and 12 produced results an order of magnitude higher than the holding pond values.

From Figure 7.1, it appears there is no marked difference between the controls and the effluent-affected sample results, with the exceptions of site 1 & 12 results. A paired two sample t-test (Appendix 4) was used to compare the distribution of the control samples with the distribution of the effluent-affected samples to test the hypothesis that the difference in their means is due to random chance and not due to a causative event. Log values of the *E. coli* counts were used since they provided a more approximate 'normal distribution' of the data as well as reducing the influence of extreme outlying data. For the control samples, the log mean = 1.876, log variance = 0.526 and for the effluent-affected samples, the log mean = 2.592, log variance = 0.854. The result for a one-tailed test was $t_{1,16} = -2.027$, $P = 0.0386$. That is, there is a corresponding 96.1% chance that the difference is due to a causative factor. Antilogging the means results in a geometric mean of 75 cfu/100mL for the control samples and 391 cfu/100 mL eq. (median = 120 cfu/100 mL eq.) for the effluent-affected samples. The increase in the means is approximately 5 fold.

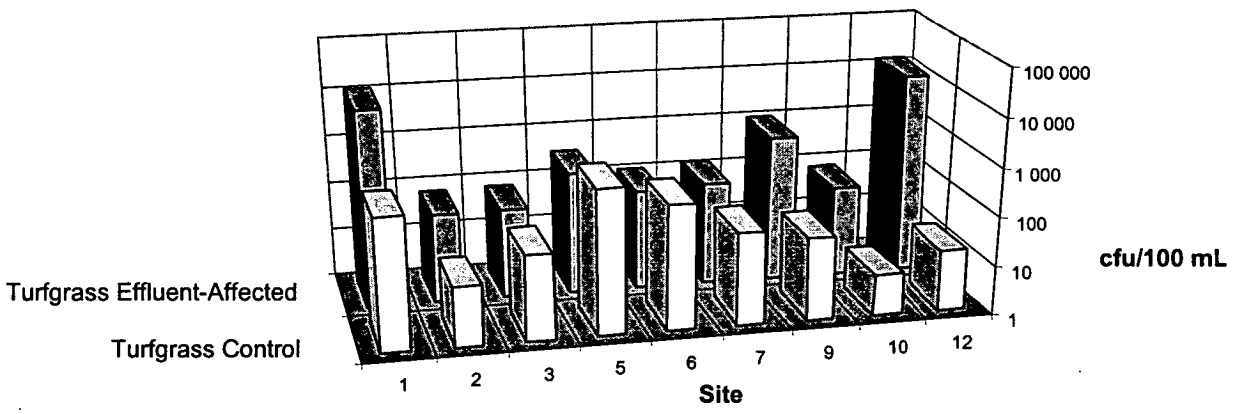

FIGURE 7.1 - Comparison between turfgrass control and effluent-affected *E. coli* results (Round 3)

Ideally, more samples would be necessary to make firmer conclusions. Statisticians usually require the standard error to be $SE \leq 10\%$ of the mean in making definite conclusions.

For the control samples, $SE = \sqrt{\frac{\sigma^2}{n}} = \sqrt{\frac{0.526}{9}} = 0.241 = 13\%$ of the mean.

For the effluent-affected samples, $SE = \sqrt{\frac{0.854}{9}} = 0.308 = 12\%$ of the mean.

The standard errors indicate more samples need to be analysed for a more robust result. Yet the errors are sufficiently close to 10% of the mean to provide a fair indication of the true difference in the means. (Note: any result expressed as '<X' in the Result Tables was adjusted to half the maximum value, that is 'X/2', for all mathematical calculations).

It is important to note that the turfgrass was considerably wet after 2.0 mm of rainfall occurred just before irrigation between 6–7 p.m,. thus helping to dilute the irrigant. The amount of irrigant applied varied from 2.3 to 8.1 mm from site to site, depending on the degree of overlap between irrigators (Result Table 2.2). The ratio between the amount of rainfall and irrigant applied would then reduce FC/*E. coli* concentrations by 1.25 to 1.90 times. By removing the effects of dilution due to the rain, by taking the average of the dilution ratio (1.25 + 1.9)/2 = 1.58, the adjusted turfgrass mean FC/*E. coli* concentration after irrigation becomes 391 x 1.58 = 616 cfu/100 mL eq.

A similar t-test (Appendix 4) was used to test whether or not the difference in the means of the effluent-affected irrigant and the effluent-affected turfgrass result was due

to chance. Again log values were used. The one-tailed test produced the result, $t_{1,16}$ = 1.205, P = 0.131. That is, there is a 13.1% probability that the difference in the means is due to chance. On the basis of a 95% confidence interval this indicates a that there are no particular set of driving factors that causes significantly lower counts of FC/*E. coli* on the turfgrass than in the irrigant water. After antilogging the means, a 3 fold difference in the means can be seen (1 069 cfu/100mL and 391 cfu/100 mL for the irrigant samples and turfgrass samples respectively). If the rainfall adjusted figure of 616 cfu/100 mL eq. is used the null hypothesis that the samples are taken from the same population would be the same.[3]

7.6.4 Soils

E. coli, in particular, was not detected both before and after irrigation providing a similar picture to Round 2. Nevertheless, FC were detected before irrigation at sites 3, 5, 7 & 10 recording counts of 70, 70, 150 & 200 cfu/g of soil respectively. After irrigation three sites had detectable FC levels of 20, 400 & 500 cfu/g at sites 1, 9 &10 respectively. At sites 9 & 10, FC counts increased from <10 to 400 cfu/g and 200 to 500 cfu/g of soil respectively.

7.6.5 Golf Balls and Players' Hands

Sample results for FC/*E. coli* again show essentially no detectable signs of faecal contamination on golf balls or on players hands except for a small count of 2 cfu/50 cm^2 on the morning before irrigation on one golf ball and 3 cfu/50 cm^2 on the morning after irrigation on another golf ball, and 1 cfu/100 cm^2 on one player's hand at midday after irrigation.

7.6.6 Aerosols

No aerosolised faecal coliforms were detectable at head height for all sites, before and after irrigation, morning, midday or in the afternoon.

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[3] The dilution affect from dew is ignored assuming it is a relatively small contributor and that the amount is the same for sampling Days 2 and 3.

RESULT TABLE 1.3 - SEWAGE TREATMENT PLANT, HOLDING POND AND CREEK SAMPLE RESULTS (ROUND 3)

			Microbiological results		Physico-chemical data				
Sample Description	Sample Code	Time taken	Faecal coliforms/ 100 mL	*E. coli*/ 100 mL	Water temp. °C	pH	K (Conductivity) µS/cm	Turbidity FTU	Comments
Sewage treatment plant effluent	STP 1	26/03 10:50 AM	7 600	1 900	17.9	7.6	798	Quite turbid	
	STP 2	26/03 1:35 PM	20	20	19.5	7.8	818	Quite turbid	
Holding pond effluent	HP 1	26/03 7:55 PM	2 600	2 600	17.6	7.7	953	62	Greens and F1 irrigated
	HP 2	27/03 12:15 AM	1 900	1 900	19.2	7.9	976	43	F3 & F5 irrigated
	HP 3	27/03 6:00 AM	1 900	1 900	15.3?	7.6	1 001	53	F2 irrigated
Control (before irrigation)									
Date: 26/3/96			Previous 24 hrs rainfall: 0.0 mm		Weather conditions: Fine and cloudy				
Creek water	CC 1	1:55 PM	520	520	21.9	7.6	1 083	Quite turbid	Pond on 7th
	CC 2	nt	nt	nt	nt	nt	nt	nt	Creek dry
	CC 3	nt	nt	nt	nt	nt	nt	nt	Creek dry
	CC 4	nt	nt	nt	nt	nt	nt	nt	Creek dry
		nt = not tested							
Effluent Affected (after irrigation)									
Date: 27/3/96			Previous 24 hrs rainfall: 2.0 mm		Weather conditions: Sunny but hazy				
Creek water	CT 1	3:30 PM	1 500	1 500	22.8	8.3	1 013	Quite turbid	Pond on 7th
	CT 2	nt	nt	nt	nt	nt	nt	nt	Creek dry
	CT 3	nt	nt	nt	nt	nt	nt	nt	Creek dry
	CT 4	nt	nt	nt	nt	nt	nt	nt	Creek dry

Irrigation on Tuesday night: All greens were irrigated first for 16 min on 8 minute repeats commencing at 9pm. Fairway 1 was set to irrigate for 10:15 pm, fairways 3 & 5 were set to irrigate at 1 am and fairway 2 was set to irrigate for 3:45am. All irrigators set for 15 minutes.

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RESULT TABLE 2.1 - IRRIGANT, TURFGRASS, SOIL SAMPLE RESULTS (ROUND 1)

Control (before irrigation)

Date: 11/10/95 Previous 24 hrs rainfall: 3.6 mm Weather conditions: Fine, Some cloud

		Microbiological results							Physico-chemical data											
		Irrigant T*		Turgrass G		Soils S[t]														
Site	Time taken	Faecal coliforms /100 mL	*E. coli* /100 mL	Faecal coliforms /100 mL	*E. coli* /100 mL	Time taken	Faecal coliforms /g of soil	*E. coli* /g of soil	Air Temp. °C	Irrigant pH	Irrigant K[e] (µS/cm)[#]	Irrigant turbidity	Soil Temp. (°C)	Soil pH[$]	Soil K[e] (dS/m @ 25°C)[$]	Soil Moisture (dry basis) (%)	Humidity (%)	Light (lux)	Wind speed (m/s)	Comments
1	8:05 AM	<10	<10	nt	nt	6:30 PM	<10	<10	nt	5.1	153	Clear	16.6	6.2	0.098	51.7	nt	22 500	nt	
2	8:04 AM	<10	<10	nt	nt	6:35 PM	<10	<10	nt	4.9	137	Clear	17.7	6.1	0.133	51.2	nt	26 000	nt	
3	8:02 AM	<10	<10	nt	nt	6:40 PM	10	10	nt	5.3	126	Clear	15.5	5.9	0.196	56.3	nt	20 500	nt	
4	8:01 AM	<10	<10	nt	nt	6:45 PM	<10	<10	nt	4.9	228	Clear	15.7	5.6	0.541	100.0	nt	26 800	nt	
5	7:59 AM	<10	<10	nt	nt	6:50 PM	<10	<10	nt	5.0	232	Clear	14.3	6.3	0.128	56.7	nt	16 600	nt	
6	7:54 AM	<10	<10	nt	nt	6:55 PM	<10	<10	nt	4.9	183	Clear	16.3	5.7	0.109	85.7	nt	4 000	nt	
7	7:52 AM	<10	<10	nt	nt	7:00 PM	<10	<10	nt	4.8	159	Clear	15.5	5.6	0.487	80.7	nt	5 400	nt	
8	7:49 AM	<10	<10	nt	nt	7:05 PM	<10	<10	nt	5.1	196	Clear	14.0	6.0	0.072	23.4	nt	19 400	nt	
9	7:47 AM	<10	<10	nt	nt	7:10 PM	<10	<10	nt	5.0	151	Clear	14.8	6.1	0.187	58.8	nt	5 500	nt	
10	7:45 AM	<10	<10	nt	nt	7:15 PM	100	100	nt	5.0	272	Clear	14.7	6.0	0.283	192.3	nt	4 100	nt	Quite boggy
11	7:42 AM	<10	<10	nt	nt	7:20 PM	<10	<10	nt	4.9	126	Clear	16.1	6.1	0.104	76.5	nt	16 000	nt	
12	7:39 AM	<10	<10	nt	nt	7:25 PM	<10	<10	nt	4.9	110	Clear	14.6	6.7	0.129	52.9	nt	10 500	nt	

* = Rainwater

[$] Based on 1:5 soil to water ratio

[#] Samples corrected for Na EDTA & Na thiosulfate based on regression analysis (Appendix 6).

Effluent Affected (after irrigation)

Date: 12/10/95 Previous 24 hrs rainfall: 0.0 mm Weather conditions: Overcast

1	7:40 AM	2 400	2 400	nt	nt	7:45 AM	<10	<10	nt	6.7	2278	Slightly cloudy	10.4	6.2	0.096	50.4	nt	24 000	nt	
2	7:50 AM	2 300	2 300	nt	nt	7:50 AM	<10	<10	nt	5.0	2616	Slightly cloudy	10.8	6.1	0.117	62.7	nt	40 900	nt	
3	8:00 AM	700	700	nt	nt	8:00 AM	<10	<10	nt	4.6	3231	Slightly cloudy	9.5	5.9	0.180	56.6	nt	17 700	nt	
4	8:05 AM	1 900	1 900	nt	nt	8:05 AM	<10	<10	nt	nt	nt	Slightly cloudy	9.1	6.0	0.286	94.8	nt	17 000	nt	
5	8:10 AM	nt[&]	nt[&]	nt	nt	8:10 AM	<10	<10	nt	nt	nt	Slightly cloudy	8.2	6.4	0.171	48.2	nt	20 000	nt	
6	8:20 AM	1 600	1 600	nt	nt	8:20 AM	10	10	nt	nt	nt	Clear with particulates	8.6	5.7	0.103	76.2	nt	15 000	nt	
7	8:25 AM	1 200	1 200	nt	nt	8:25 AM	200	200	nt	nt	nt	Clear with particulates	9.2	5.6	0.481	136.6	nt	18 400	nt	
8	8:30 AM	nt[&]	nt[&]	nt	nt	8:30 AM	<10	<10	nt	nt	nt	-	8.7	6.1	0.063	27.7	nt	19 000	nt	
9	8:35 AM	nt[&]	nt[&]	nt	nt	8:35 AM	<10	<10	nt	nt	nt	-	10.7	5.8	0.178	49.8	nt	21 000	nt	
10	8:45 AM	3 100	3 100	nt	nt	8:45 AM	<10	<10	nt	6.8	2206	Clear with particulates	8.2	6.2	0.283	168.0	nt	29 000	nt	
11	8:50 AM	2 300	2 300	nt	nt	8:50 AM	<10	<10	nt	nt	nt	Clear with particulates	9.9	6.0	0.089	79.6	nt	36 000	nt	
12	8:55 AM	nt[&]	nt[&]	nt	nt	8:55 AM	<10	<10	nt	nt	nt	-	9.9	6.8	0.155	42.2	nt	36 000	nt	

[&] Greens for some reason were not irrigated when programmed to do so

[t] Three samples 5cm deep were taken per site for soil samples then 10g of soil was mixed with 90g of peptone water before analysis.

[e] K = conductivity (a measurement of the salinity) of water or soils. Different units are used for conductivity of water and soils. dS/m = 1000 µS/cm

Prepared by Simon Marrable 29/08/96

RIVERSIDE GOLF COURSE MICROBIOLOGICAL DATASET

RESULT TABLE 2.2 - IRRIGANT, TURFGRASS, SOIL SAMPLE RESULTS (ROUND 2)

Control (before irrigation)

Date: 8/11/95 — Previous 24 hrs rainfall: 1.6 mm — Weather conditions: Overcast with light showers

		Microbiological results								Physico-chemical data											
		Irrigant T		Turgrass G				Soils S[1]													
Site	Time taken	Faecal coliforms /100 mL	*E. coli* /100 mL	Faecal coliforms /100 cm^2 of grass	*E. coli* /100 cm^2 of grass	Faecal coliforms /100 mL eq	*E. coli* /100 mL eq	Faecal coliforms /g of soil	*E. coli* /g of soil	Air Temp. °C	Irrigant pH	Irrigant K (µS/cm)[#]	Irrigant turbidity	Soil Temp. (°C)	Soil pH[$]	Soil K (dS/m @ 25°C)[$]	Soil Moisture (dry basis) (%)	Humidity (%)	Light (lux)	Wind speed (m/s)	Comments
1	7:30 AM	<10	<10	<1 400	<1 400	<1 800	<1 800	<10	<10	10.5	5.1	1 101	Clear	13.8	6.2	0.227	49.3	100	11900	0.2	Light showers
2	7:45 AM	<10	<10	<1 400	<1 400	<3 600	<3 600	<10	<10	10.5	5.0	950	Clear	14.2	6.2	0.165	43.3	100	12400	0.8	
3	8:00 AM	<10	<10	<2 000	<2 000	<2 400	<2 400	<10	<10	11.0	5.0	932	Clear	13.7	7.7	0.148	36.8	100	12600	0.2	
4	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	
5	8:10 AM	<10	<10	<2 000	<2 000	<3 900	<3 900	<10	<10	11.0	4.9	675	Clear	13.1	6.8	0.121	20.7	100	12500	0.4	
6	8:20 AM	<10	<10	<1 400	<1 400	<4 000	<4 000	<10	<10	11.0	4.8	690	Clear	13.6	5.7	0.179	71.7	100	13800	Still	Stopped Raining
7	8:30 AM	<10	<10	<1 400	<1 400	<1 800	<1 800	<10	<10	11.5	4.9	756	Clear	13.7	5.9	0.424	91.3	100	13900	Still	
8	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	
9	8:40 AM	140	140	<2 000	<2 000	<8 500	<8 500	<10	<10	11.5	5.1	nt	Slightly Turbid	13.9	6.5	0.186	48.1	100	14300	Still	
10	8:50 AM	<10	<10	4 000	4 000	7 300	7 300	<10	<10	11.5	5.0	693	Clear	13.5	6.1	0.372	192.1	95	16200	1.0	
11	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	
12	9:00 AM	<10	<10	<2 000	<2 000	<6 100	<6 100	<10	<10	12.0	4.9	748	Slightly Turbid	14.1	6.8	0.142	19.8	95	21200	1.0	

[$] Based on 1:5 soil to deionised water ratio

[#] Samples corrected for Na EDTA & Na thiosulfate based on regression analysis (Appendix 6).

Effluent Affected (after irrigation)

Date: 9/11/95 — Previous 24 hrs rainfall: 0.0 mm — Weather conditions: Fine and overcast (foggy during sample collection)

																					Irrigant applied (mm)
1	7:30 AM	410	410	<1 400	<1 400	<1 800	<1 800	<10	<10	14.5	7.0	1 475	Slightly turbid & yellow	nt	6.5	0.168	44.8	100	13100	Still	7.2
2	7:45 AM	1 000	1 000	<1 400	<1 400	<3 600	<3 600	<10	<10	14.5	5.7	1 745	Slightly turbid & yellow	nt	6.2	0.128	35.1	100	12800	0.0-1.0	3.5
3	7:55 AM	1 200	1 200	<2 000	<2 000	<2 400	<2 400	<10	<10	14.5	6.5	1 868	Slightly turbid & yellow	nt	7.1	0.107	42.1	100	11700	0.2-1.2	8.1
4	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	
5	8:05 AM	510	510	<2 000	<2 000	<3 900	<3 900	<10	<10	15.5	5.9	1 653	Slightly turbid & yellow	nt	6.7	0.092	20.4	100	23000	1.0	5.1
6	8:10 AM	430	430	<1 400	<1 400	<4 000	<4 000	<10	<10	15.5	5.7	1 981	Slightly turbid & yellow	nt	5.7	0.176	68.4	100	12000	0.5-1.5	3.2
7	8:25 AM	470	470	<1 400	<1 400	<1 800	<1 800	<10	<10	15.0	6.5	1 397	Slightly turbid & yellow	nt	5.9	0.339	102.7	100	16000	1.0-2.0	7.2
8	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	
9	8:30 AM	150	150	42 000	42 000	180 000	180 000	<10	<10	15.0	5.3	1 981	Slightly turbid & yellow	nt	6.6	0.196	73.1	100	27000	0.5	2.3
10	8:40 AM	400	400	<1 400	<1 400	<1 500	<1 500	<10	<10	15.5	6.4	1 417	Slightly turbid & yellow	nt	6.5	0.384	174.9	100	18000	1.0-1.5	8.1
11	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	
12	8:50 AM	410	410	<2 000	<2 000	<6 100	<6 100	<10	<10	11.5	5.5	1 806	Slightly turbid & yellow	nt	6.8	0.194	20.1	100	25800	1.0-2.0	3.2

[1] Three samples 5cm deep were taken per site for soil samples then 10g of soil was mixed with 90g of peptone water before analysis.

[b] Initially 10g of turfgrass was mixed with 90 mL of peptone water and then filtered. One gram of turfgrass was then converted to cfu/100mL equivalent in order to compare the results with the irrigant microbial levels. This was done by taking into account the ratio of the surface area to the mass of turfgrass and the amount of irrigant applied to each site. Only analysing 10g of turfgrass leads to a very insensitive method of detecting the bacteria. Thus a new sampling method was employed for the last sampling round.

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RESULT TABLE 2.3 - IRRIGANT, TURFGRASS, SOIL SAMPLE RESULTS (ROUND 3)

Control (before irrigation)

Date: 26/3/96 Previous 24 hrs rainfall: 0.0 mm Weather conditions: Light cloud

		Microbiological results								Physico-chemical data											
		Irrigant T		Turgrass G				Soils S[†]													
Site	Time taken	Faecal coliforms /100 mL	*E. coli* /100 mL	Faecal coliforms /100 cm^2 of grass	*E. coli* /100 cm^2 of grass	Faecal coliforms /100 mL eq	*E. coli* /100 mL eq	Faecal coliforms /g of soil	*E. coli* /g of soil	Air Temp. °C	Irrigant pH	Irrigant K (µS/cm)[#]	Irrigant turbidity	Soil Temp. (°C)	Soil pH[$]	Soil K (dS/m @ 25°C)[$]	Soil Moisture (dry basis) (%)	Humidity (%)	Light (lux)	Wind speed (m/s)	Comments
1	7:10 AM	nt	nt	350	350	480*	480*	<10	<10	13.0	nt	nt	nt	16.7	16.3	0.0746	45.4	95	76	nt	Grass wet
2	7:25 AM	nt	nt	<12	<12	<33*	<33*	<10	<10	13.0	nt	nt	nt	15.9	15.5	0.112	20.2	95	360	nt	Soil looked dry
3	7:35 AM	nt	nt	46	46	56	56	70	<10	13.0	nt	nt	nt	15.5	15.1	0.0885	40.5	95	780	nt	Sun yet to rise
4	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	
5	7:42 AM	nt	nt	460	460	920	920	70	<10	12.5	nt	nt	nt	14.8	14.4	0.11	20.4	95	1 400	nt	
6	7:50 AM	nt	nt	120	120	360	360	<10	<10	12.0	nt	nt	nt	13.0	12.6	0.173	37.5	95	2 340	nt	
7	7:55 AM	nt	nt	<120	<120	<160*	<160*	150	<10	13.0	nt	nt	nt	15.2	14.8	0.108	62.7	95	3 300	nt	Noted as very moist
8	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	
9	8:05 AM	nt	nt	11	11	50*	50*	<10	<10	13.0	nt	nt	nt	15.7	15.3	0.0752	26.0	95	6 050	nt	
10	8:13 AM	nt	nt	<12	<12	<14	<14	200	<10	13.5	nt	nt	nt	15.4	15.0	0.182	110.9	95	9 160	nt	Hazy - no direct sunlight
11	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	
12	8:25 AM	nt	nt	<12	<12	<36*	<36*	<10	<10	14.5	nt	nt	nt	15.1	14.7	0.0505	26.8	95	1 460	nt	Grass still wet

* Retest on 28/3

[$] Based on 1:5 soil to deionised water ratio

[*] Quite calm throughout sampling run

Effluent Affected (after irrigation)

[#] Samples corrected for Na EDTA & Na thiosulfate based on regression analysis (Appendix 6).

Date: 27/3/96 Previous 24 hrs rainfall: 2.0 mm Weather conditions: Foggy but fine

1	7:15 AM	1 300	1 300	7 800	7 800	11 000	11 000	20	<10	11.5	7.5	nt	nt	15.1	6.7	0.125	24.1	95	233	nt	Not enough sample to measure K
2	7:25 AM	900	900	23	23	66	66	<10	<10	11.0	6.8	1 348	nt	14.4	6.5	0.161	25.6	100	720	nt	
3	7:35 AM	7 300	7 300	<120	<120	<140*	<140*	<10	<10	11.0	7.0	848	nt	14.5	7.2	0.109	36.7	100	1 440	nt	Still misty
4	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	
5	7:47 AM	900	900	160	160	320	320	<10	<10	11.0	6.8	1 164	nt	13.8	6.4	0.085	28.4	100	2 500	nt	Sun yet to rise
6	8:30 AM	600	600	34	34	110	110	<10	<10	12.5	7.0	1 137	nt	13.0	6.1	0.181	34.1	100	6 370	nt	Overcast
7	8:25 AM	1 200	1 200	92	92	130	130	<10	<10	12.0	7.0	919	nt	13.2	6.4	0.103	52.8	100	5 170	nt	
8	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	
9	8:15 AM	500	500	230	230	1 000	1 000	400	<100	12.0	6.5	1 419	nt	14.6	7.0	0.088	30.6	100	4 400	nt	Foggy
10	8:05 AM	1 100	1 100	<120	<120	<140*	<140*	500	<100	12.0	7.4	nt	nt	13.9	6.5	0.301	148.7	95	3 590	nt	Not enough sample to measure K
11	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	nt	
12	7:55 AM	600	600	4 100	4 100	13 000	13 000	<10	<10	12.0	6.6	1 233	nt	13.9	7.1	0.075	23.3	95	3 420	nt	Very foggy

[†] Three samples 5cm deep were taken per site for soil samples then 10g of soil was mixed with 90g of peptone water before analysis.

RESULT TABLE 3.1 - GOLF BALLS AND PLAYERS HANDS SAMPLE RESULTS (ROUND 1)

Control (before irrigation)
Date: 11/10/95 Previous 24 hrs rainfall: 3.6 mm Weather conditions: Fine, Some cloud

		Players golf balls after 5th hole			Players hands before teeing off*			Players hands after 5th hole*			
Player	Time sample taken after 5th hole	Sample Code	Faecal coliforms /50 cm^2 [t]	*E. coli* /50 cm^2 [t]	Sample Code	Faecal coliforms /200 cm^2	*E. coli* /200 cm^2	Sample Code	Faecal coliforms /200 cm^2	*E. coli* /200 cm^2	Comments
Mid morning sampling run (9-11AM)											
1	10:25 AM	BMC 1	<2	<2	PMCB 1	<1	<1	PMCA 1	<1	<1	
2	10:20 AM	BMC 2	nt	nt	PMCB 2	<1	<1	PMCA 2	<1	<1	Player lost ball
3	nt	BMC 3	nt	nt	PMCB 3	nt	nt	PMCA 3	nt	nt	
4	nt	BMC 4	nt	nt	PMCB 4	nt	nt	PMCA 4	nt	nt	
Midday sampling run (11PM-2PM)											
1	1:55 PM	BOC 1	<2	<2	POCB 1	<1	<1	POCA 1	<1	<1	
2	1:45 PM	BOC 2	<2	<2	POCB 2	<1	<1	POCA 2	<1	<1	
3	nt	BOC 3	nt	nt	POCB 3	nt	nt	POCA 3	nt	nt	
4	nt	BOC 4	nt	nt	POCB 4	nt	nt	POCA 4	nt	nt	
Mid afternoon sampling run (2-4PM)											
1	4:35 PM	BAC 1	<2	<2	PACB 1	<1	<1	PACA 1	<1	<1	
2	4:45 PM	BAC 2	<2	<2	PACB 2	<1	<1	PACA 2	<1	<1	
3	nt	BAC 3	nt	nt	PACB 3	nt	nt	PACA 3	nt	nt	
4	nt	BAC 4	nt	nt	PACB 4	nt	nt	PACA 4	nt	nt	
Effluent Affected (after irrigation)											
Date: 12/10/95 Previous 24 hrs rainfall: 0.0 mm Weather conditions: Overcast											
Mid morning sampling run (9-11AM)											
1	10:25 AM	BMT 1	<2	<2	PMTB 1	<1	<1	PMTA 1	<1	<1	
2	10:25 AM	BMT 2	<2	<2	PMTB 2	<1	<1	PMTA 2	<1	<1	
3	nt	BMT 3	nt	nt	PMTB 3	nt	nt	PMTA 3	nt	nt	
4	nt	BMT 4	nt	nt	PMTB 4	nt	nt	PMTA 4	nt	nt	
Midday sampling run (11PM-2PM)											
1	12:40 PM	BOT 1	<2	<2	POTB 1	<1	<1	POTA 1	<1	<1	
2	12:40 PM	BOT 2	<2	<2	POTB 2	<1	<1	POTA 2	<1	<1	
3	nt	BOT 3	nt	nt	POTB 3	nt	nt	POTA 3	nt	nt	
4	nt	BOT 4	nt	nt	POTB 4	nt	nt	POTA 4	nt	nt	
Mid afternoon sampling run (2-4PM)											
1	3:05 PM	BAT 1	<2	<2	PATB 1	<1	<1	PATA 1	<1	<1	
2	3:05 PM	BAT 2	<2	<2	PATB 2	<1	<1	PATA 2	<1	<1	
3	nt	BAT 3	nt	nt	PATB 3	nt	nt	PATA 3	nt	nt	
4	nt	BAT 4	nt	nt	PATB 4	nt	nt	PATA 4	nt	nt	

[t] Golf ball diameter = 42.5 mm

* Swabbed both hands 300 cm^2 each, 200 cm^2 is based on 2/3 area of palms, 10mL of 15mL solution was filtered.

RESULT TABLE 3.2 - GOLF BALLS AND PLAYERS HANDS SAMPLE RESULTS (ROUND 2)

Control (before irrigation)
Date: 8/11/95 Previous 24 hrs rainfall: 1.6 mm Weather conditions: Overcast with light showers

		Players golf balls after 5th hole[1]			Players hands before teeing off*			Players hands after 5th hole*			
Player	Time sample taken after 5th hole	Sample Code	Faecal coliforms /50 cm^2	*E. coli* /50 cm^2	Sample Code	Faecal coliforms /200 cm^2	*E. coli* /200 cm^2	Sample Code	Faecal coliforms /200 cm^2	*E. coli* /200 cm^2	Comments
Mid morning sampling run (9-11AM)											
1	11:10 AM	BMC 1	<2	<2	PMCB 1	<1	<1	PMCA 1	<1	<1	
2	11:10 AM	BMC 2	<2	<2	PMCB 2	<1	<1	PMCA 2	<100	<100	
3	nt	BMC 3	nt	nt	PMCB 3	nt	nt	PMCA 3	nt	nt	Player not available
4	nt	BMC 4	nt	nt	PMCB 4	nt	nt	PMCA 4	nt	nt	Player not available
Midday sampling run (11PM-2PM)											
1	1:50 PM	BOC 1	<2	<2	POCB 1	<1	<1	POCA 1	<1	<1	
2	1:50 PM	BOC 2	<2	<2	POCB 2	<1	<1	POCA 2	<1	<1	
3	1:50 PM	BOC 3	<2	<2	POCB 3	<1	<1	POCA 3	<1	<1	
4	1:50 PM	BOC 4	<2	<2	POCB 4	<1	<1	POCA 4	<1	<1	
Mid afternoon sampling run (2-4PM)											
1	4:00 PM	BAC 1	<2	<2	PACB 1	<1	<1	PACA 1	<1	<1	
2	4:00 PM	BAC 2	<2	<2	PACB 2	<1	<1	PACA 2	<1	<1	
3	4:00 PM	BAC 3	<2	<2	PACB 3	<1	<1	PACA 3	<1	<1	
4	4:00 PM	BAC 4	<2	<2	PACB 4	<1	<1	PACA 4	<1	<1	
Effluent Affected (after irrigation)											
Date: 9/11/95 Previous 24 hrs rainfall: 0.0 mm Weather conditions: Fine and overcast											
Mid morning sampling run (9-11AM)											
1	11:00 AM	BMT 1	<2	<2	PMTB 1	<1	<1	PMTA 1	<1	<1	
2	11:00 AM	BMT 2	<2	<2	PMTB 2	<1	<1	PMTA 2	<1	<1	
3	11:00 AM	BMT 3	<2	<2	PMTB 3	<1	<1	PMTA 3	<1	<1	
4	nt	BMT 4	nt	nt	PMTB 4	nt	nt	PMTA 4	nt	nt	Player not available
Midday sampling run (11PM-2PM)											
1	1:45 PM	BOT 1	<2	<2	POTB 1	<1	<1	POTA 1	<1	<1	
2	1:45 PM	BOT 2	<2	<2	POTB 2	<1	<1	POTA 2	<1	<1	
3	1:45 PM	BOT 3	<2	<2	POTB 3	<1	<1	POTA 3	<1	<1	
4	1:45 PM	BOT 4	<2	<2	POTB 4	<1	<1	POTA 4	<1	<1	
Mid afternoon sampling run (2-4PM)											
1	3:35 PM	BAT 1	4	<2	PATB 1	<1	<1	PATA 1	<1	<1	
2	3:35 PM	BAT 2	<2	<2	PATB 2	<1	<1	PATA 2	<1	<1	
3	3:35 PM	BAT 3	<2	<2	PATB 3	<1	<1	PATA 3	<1	<1	I touched the ball
4	3:35 PM	BAT 4	<2	<2	PATB 4	<1	<1	PATA 4	<1	<1	

RESULT TABLE 3.3 - GOLF BALLS AND PLAYERS HANDS SAMPLE RESULTS (ROUND 3)

Control (before irrigation)
Date: 26/3/96 Previous 24 hrs rainfall: 0.0 mm Weather conditions: Light cloud

		Players golf balls after 5th hole[1]			Players hands before teeing off*			Players hands after 5th hole*			
Player	Time sample taken after 5th hole	Sample Code	Faecal coliforms /50 cm^2	*E. coli* /50 cm^2	Sample Code	Faecal coliforms /200 cm^2	*E. coli* /200 cm^2	Sample Code	Faecal coliforms /200 cm^2	*E. coli* /200 cm^2	Comments
Mid morning sampling run (9-11AM)											
1	10:10 AM	BMC 1	2	2	PMCB 1	<1	<1	PMCA 1	<1	<1	
2	10:10 AM	BMC 2	<2	<2	PMCB 2	<1	<1	PMCA 2	<1	<1	
3	10:10 AM	BMC 3	<2	<2	PMCB 3	<1	<1	PMCA 3	<1	<1	
4	10:10 AM	BMC 4	<2	<2	PMCB 4	<1	<1	PMCA 4	<1	<1	
Midday sampling run (11PM-2PM)											
1	12:30 PM	BOC 1	<2	<2	POCB 1	<1	<1	POCA 1	<1	<1	
2	12:30 PM	BOC 2	<2	<2	POCB 2	<1	<1	POCA 2	<1	<1	
3	12:30 PM	BOC 3	<2	<2	POCB 3	<1	<1	POCA 3	<1	<1	
4	nt	BOC 4	nt	nt	POCB 4	nt	nt	POCA 4	nt	nt	Player not available
Mid afternoon sampling run (2-4PM)											
1	3:25 PM	BAC 1	<2	<2	PACB 1	<1	<1	PACA 1	<1	<1	
2	3:25 PM	BAC 2	<2	<2	PACB 2	<1	<1	PACA 2	<1	<1	
3	nt	BAC 3	nt	nt	PACB 3	nt	nt	PACA 3	nt	nt	Player not available
4	nt	BAC 4	nt	nt	PACB 4	nt	nt	PACA 4	nt	nt	Player not available

Effluent Affected (after irrigation)
Date: 27/3/96 Previous 24 hrs rainfall: 2.0 mm Weather conditions: Sunny but hazy

Mid morning sampling run (9-11AM)											
1	10:30 AM	BMT 1	<2	<2	PMTB 1	<1	<1	PMTA 1	<1	<1	
2	10:30 AM	BMT 2	3	3	PMTB 2	<1	<1	PMTA 2	<10	<10	
3	10:30 AM	BMT 3	<2	<2	PMTB 3	<1	<1	PMTA 3	<1	<1	
4	10:30 AM	BMT 4	<2	<2	PMTB 4	<1	<1	PMTA 4	<1	<1	
Midday sampling run (11PM-2PM)*											
1	12:35 PM	BOT 1	<2	<2	POTB 1	<1	<1	POTA 1	<1	<1	
2	12:35 PM	BOT 2	<2	<2	POTB 2	<1	<1	POTA 2	<1	<1	
3	1:10 PM	BOT 3	<2	<2	POTB 3	<1	<1	POTA 3	<1	<1	
4	1:10 PM	BOT 4	<20	<20	POTB 4	<1	<1	POTA 4	1	1	
Mid afternoon sampling run (2-4PM)											
1	3:00 AM	BAT 1	<2	<2	PATB 1	<1	<1	PATA 1	<1	<1	
2	3:00 AM	BAT 2	<2	<2	PATB 2	<1	<1	PATA 2	<1	<1	
3	3:00 AM	BAT 3	<2	<2	PATB 3	<1	<1	PATA 3	<1	<1	
4	nt	BAT 4	nt	nt	PATB 4	<1	<1	PATA 4	<1	<1	

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RESULT TABLE 4.1 - AEROSOL SAMPLE RESULTS (ROUND 1)

Control

Date: 11/10/95 — Previous 24 hrs rainfall: 3.6 mm — Weather conditions: Fine, Some cloud

			Microbiological results		Climatological results					
Site	Time taken	Sample Code	Faecal coliforms / m^3 *	*E. coli* / m^3 *	Air Temp. °C	Humidity (%)	Wind speed (m/s)	Wind direction	Light (lux)	Comments
Mid morning sampling run (9-11AM)										
1	11:20 AM	AMC 1	< 7	< 7	16.5	63	2.0	N	85 400	
2	11:10 AM	AMC 2	< 7	< 7	15.5	72	2.5	N	80 000	
3	11:05 AM	AMC 3	< 7	< 7	15.5	63	0.5	NW	87 000	
4	10:55 AM	AMC 4	< 7	< 7	15.5	67	1.3	NW	86 400	
5	10:50 AM	AMC 5	< 7	< 7	15.0	66	4.0-5.0	WNW	78 800	
6	9:20 AM	AMC 6	< 4	< 4	12.5	68	1.2	NW	62 000	320 L sample
7	9:34 AM	AMC 7	< 4	< 4	14.5	56	1.5-2.5	NW	68 800	320 L sample
8	9:47 AM	AMC 8	< 7	< 7	14.0	56	1.0-2.0	NW	61 800	
9	9:55 AM	AMC 9	< 7	< 7	14.0	56	1.5-2.5	WNW	68 900	
10	10:38 AM	AMC 10	< 7	< 7	14.0	66	3.0-4.0	NW	76 000	
11	9:30 AM	AMC 11	< 7	< 7	14.5	62	2.0-3.0	NW	75 000	
12	10:10 AM	AMC 12	< 7	< 7	14.5	62	1.5	NNW	63 000	
Midday sampling run (11AM-2PM)										
1	2:15 PM	AOC 1	< 7	< 7	17.0	59	1.0-2.0	NNW	82 500	
2	2:10 PM	AOC 2	< 7	< 7	16.5	58	1.0-2.0	N	89 000	
3	2:00 PM	AOC 3	< 7	< 7	17.0	59	1.5-2.5	W	13 000	Cloud
4	1:37 PM	AOC 4	< 7	< 7	17.0	47	1.0-2.0	W	30 000	Cloud
5	1:30 PM	AOC 5	< 7	< 7	16.5	55	1.5-2.5	N	32 000	Cloud
6	1:20 PM	AOC 6	< 7	< 7	18.0	49	2.0-3.0	SW	24 200	Cloud
7	1:15 PM	AOC 7	< 7	< 7	17.5	44	2.5-3.5	NW	108 000	
8	1:10 PM	AOC 8	< 7	< 7	19.0	50	1.5-2.5	SSW	99 500	
9	12:55 PM	AOC 9	< 7	< 7	18.0	53	0.0-1.0	W	105 900	
10	12:45 PM	AOC 10	< 7	< 7	18.0	49	2.5-3.5	N	100 000	
11	12:04 PM	AOC 11	< 7	< 7	16.5	50	1.5-2.5	NW	104 000	
12	12:10 PM	AOC 12	< 7	< 7	16.5	55	1.5-2.5	NW	93 500	
Mid afternoon sampling run (2-4PM)										
1	3:45 PM	AAC 1	< 7	< 7	16.5	58	2.5-3.5	N	35 000	
2	3:50 PM	AAC 2	< 7	< 7	16.5	67	2.0	NNW	64 000	Gusty
3	4:00 PM	AAC 3	< 7	< 7	16.0	62	2.0-3.0	NW	17 000	Gusty & cloudy
4	4:05 PM	AAC 4	< 7	< 7	16.0	67	4.5-5.5	NW	25 000	Gusty & cloudy
5	4:10 PM	AAC 5	< 7	< 7	15.0	62	6.0-7.0	WNW	20 000	Gusty & cloudy
6	4:15 PM	AAC 6	< 7	< 7	14.5	71	3.5-4.5	NNW	65 000	Gusty
7	4:25 PM	AAC 7	< 7	< 7	15.5	67	3.5-4.5	NW	70 000	Gusty
8	5:00 PM	AAC 8	< 7	< 7	15.5	67	7.0-8.0	NW	8 400	Shady
9	4:55 AM	AAC 9	< 7	< 7	16.0	67	3.5-4.5	NW	41 800	Sunny
10	4:50 PM	AAC 10	< 7	< 7	15.5	67	4.5-5.5	NNW	10 000	Shady
11	4:45 PM	AAC 11	< 7	< 7	15.5	67	4.5-5.5	NW	51 800	Sunny & gusty
12	4:30 PM	AAC 12	< 7	< 7	16.0	67	4.5-5.5	NNW	69 000	Sunny & gusty

* 160 L converted to 1m^3

Effluent Affected

Date: 12/10/95 — Previous 24 hrs rainfall: 0.0 mm — Weather conditions: Overcast

Mid morning sampling run (9-11AM)										
1	9:30 AM	AMT 1	< 7	< 7	10.5	72	0.5-1.5	SW	60 000	Grass just cut
2	9:40 AM	AMT 2	< 7	< 7	10.0	71	1.0-2.0	E	61 000	Grass just cut
3	9:50 AM	AMT 3	< 7	< 7	11.0	78	1.0-2.0	E	67 500	Grass just cut
4	9:55 AM	AMT 4	< 7	< 7	12.5	74	0.5-1.5	SSW	76 000	Grass just cut
5	10:00 AM	AMT 5	< 7	< 7	11.5	74	1.5-2.5	SE	35 000	Cloudy
6	10:55 AM	AMT 6	< 7	< 7	13.5	66	0.5-1.5	W	72 000	Cloudy
7	10:40 AM	AMT 7	< 7	< 7	12.5	68	0.8	NNE-NW	36 500	Cloudy
8	10:35 AM	AMT 8	< 7	< 7	12.0	68	0.0-1.0	NE	103 500	Sunny
9	10:30 AM	AMT 9	< 7	< 7	11.5	68	0.5-1.5	N	37 400	Cloudy
10	10:25 AM	AMT 10	< 7	< 7	13.0	64	Still	-	80 000	Bit cloudy
11	10:07 AM	AMT 11	13	< 7	12.0	68	0.5-1.5	NE	70 000	Cloudy
12	10:20 AM	AMT 12	< 7	< 7	13.0	68	0.5	E	80 000	Sunny
Midday sampling run (11AM-2PM)										
1	11:45 AM	AOT 1	< 7	< 7	14.5	62	1.0	NW	62 300	Light cloud
2	11:52 AM	AOT 2	< 7	< 7	14.0	58	2.0	W	55 000	Light cloud
3	12:00 PM	AOT 3	< 7	< 7	15.0	58	1.5	NW	62 000	Light cloud
4	12:05 PM	AOT 4	< 7	< 7	15.5	62	0.8	W	59 000	Light cloud
5	12:15 PM	AOT 5	< 7	< 7	15.5	62	2.5	NW-N	50 000	Light cloud
6	12:20 PM	AOT 6	< 7	< 7	14.5	58	0.5-1.5	W	70 000	Light cloud
7	1:05 PM	AOT 7	< 7	< 7	15.5	58	0.5-1.5	NW	54 000	Light cloud
8	1:00 PM	AOT 8	< 7	< 7	15.0	58	2.5-3.5	NNW	58 000	Light cloud
9	12:55 PM	AOT 9	< 7	< 7	15.0	62	1.5-2.5	NW	43 000	Light cloud
10	12:50 PM	AOT 10	< 7	< 7	15.5	62	1.0	NW	43 600	Light cloud
11	12:30 PM	AOT 11	< 7	< 7	15.0	58	1.0-2.0	NNW	64 000	Light cloud
12	12:35 PM	AOT 12	< 7	< 7	15.0	68	0.5-1.5	NW	58 000	Light cloud
Mid afternoon sampling run (2-4PM)										
1	2:22 PM	AAT 1	< 7	< 7	14.0	60	2.5-7.5	NE	25 000	Overcast
2	2:27 PM	AAT 2	< 7	< 7	14.0	60	3.5	NNW	21 500	Overcast
3	2:33 PM	AAT 3	< 7	< 7	14.0	66	0.5	N	21 500	Overcast
4	2:40 PM	AAT 4	< 7	< 7	14.0	60	1.5-2.5	N	16 000	Overcast
5	2:47 PM	AAT 5	< 7	< 7	14.0	60	1.5-2.5	N	19 100	Overcast
6	2:55 PM	AAT 6	< 7	< 7	14.0	55	2.5-3.5	N	17 900	Overcast
7	3:35 PM	AAT 7	< 7	< 7	13.0	35	1.5	NNE	11 200	Overcast
8	3:30 PM	AAT 8	< 7	< 7	13.5	60	1.5	NNE	13 100	Overcast
9	3:23 PM	AAT 9	< 7	< 7	13.5	60	0.5	N	14 000	Overcast
10	3:12 PM	AAT 10	< 7	< 7	14.0	52	1.0-2.0	NE	14 000	Overcast
11	3:11 PM	AAT 11	< 7	< 7	14.0	52	1.0-2.0	NNE	14 000	Overcast
12	3:00 PM	AAT 12	< 7	< 7	14.0	52	1.5	NE	18 000	Overcast

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RESULT TABLE 4.2 - AEROSOL SAMPLE RESULTS (ROUND 2)

Control

Date: 8/11/95 — Previous 24 hrs rainfall:1.6 mm — Weather conditions: Overcast with light show

			Microbiological results		Climatological results					
Site	Time taken	Sample Code	Faecal coliforms / m^3 *	*E. coli* / m^3 *	Air Temp. °C	Humidity (%)	Wind speed (m/s)	Wind direction	Light (lux)	Comments
Mid morning sampling run (9-11AM)										
1	10:05 AM	AMC 1	< 7	< 7	13.0	84	0.8	NW	35 100	
2	10:25 AM	AMC 2	< 7	< 7	14.0	85	0.5-1.0	N-E	33 600	
3	10:35 AM	AMC 3	< 7	< 7	13.5	85	Calm	-	41 500	
4	nt	AMC 4	nt	nt	nt	nt	nt	nt	nt	
5	10:45 AM	AMC 5	< 7	< 7	14.0	80	Calm	-	50 000	
6	10:55 AM	AMC 6	< 7	< 7	14.5	81	0.8	E-ESE	48 000	
7	11:30 AM	AMC 7	< 7	< 7	16.5	73	Calm	-	70 000	
8	nt	AMC 8	nt	nt	nt	nt	nt	nt	nt	
9	11:35 AM	AMC 9	< 7	< 7	16.0	73	1.0-1.5	NNE-NE	65 000	
10	11:20 AM	AMC 10	< 7	< 7	15.0	76	0.5	NNE	60 000	
11	nt	AMC 11	nt	nt	nt	nt	nt	nt	nt	
12	11:00 AM	AMC 12	< 7	< 7	14.5	80	0.5	E-ESE	58 000	
Midday sampling run (11AM-2PM)										
1	1:00 PM	AOC 1	< 7	< 7	19.0	61	1.5	NE	117 000	
2	1:05 PM	AOC 2	< 7	< 7	18.0	65	1.5	N-NE	77 000-94 000	
3	1:10 PM	AOC 3	< 7	< 7	19.5	62	1.0-1.5	NW-NE	148 000	
4	nt	AOC 4	nt	nt	nt	nt	nt	nt	nt	
5	1:20 PM	AOC 5	< 7	< 7	19.0	66	1.5-2.5	N-NW	133 500	
6	1:30 PM	AOC 6	< 7	< 7	19.0	70	0.5-2.0	NW	104 000-130 000	
7	1:35 PM	AOC 7	< 7	< 7	18.0	68	3.0	NW-NNW	50 000	Large Cloud
8	nt	AOC 8	nt	nt	nt	nt	nt	nt	nt	
9	2:00 PM	AOC 9	< 7	< 7	18.5	69	Calm	-	15 000	Thick Cloud
10	1:55 PM	AOC 10	< 7	< 7	18.5	65	1.0-3.0	N-NW	110 000	
11	nt	AOC 11	nt	nt	nt	nt	nt	nt	nt	
12	1:40 PM	AOC 12	< 7	< 7	19.5	66	1.0-2.0	N-NW	123 500	
Mid afternoon sampling run (2-4PM)										
1	3:05 PM	AAC 1	< 7	< 7	16.0	81	1.0-2.0	N-W	25 800	
2	3:10 PM	AAC 2	< 7	< 7	16.5	77	1.0-3.0	NW-W	80 000	
3	3:20 PM	AAC 3	< 7	< 7	19.0	70	2.0	W	60 000	
4	nt	AAC 4	nt	nt	nt	nt	nt	nt	nt	
5	4:30 PM	AAC 5	< 7	< 7	18.0	73	3.0-4.0	NW	60 000-80 000	
6	4:20 PM	AAC 6	< 7	< 7	17.5	77	2.0-4.0	NW	95 000	Sunny
7	4:15 PM	AAC 7	< 7	< 7	17.5	73	4.0	WNW	80 000-95 000	
8	nt	AAC 8	nt	nt	nt	nt	nt	nt	nt	
9	4:10 PM	AAC 9	< 7	< 7	17.0	73	2.0-3.0	NW	39 500-80 000	
10	4:00 PM	AAC 10	< 7	< 7	17.5	73	3.0	NW	37 500	
11	nt	AAC 11	nt	nt	nt	nt	nt	nt	nt	
12	3:50 PM	AAC 12	< 7	< 7	17.0	77	1.0-1.5	NW	31 800	Cloudy

* 160 L converted to $1m^3$

Effluent Affected

Date: 9/11/95 — Previous 24 hrs rainfall: 0.0 mm — Weather conditions: Fine and overcast

Mid morning sampling run (9-11AM)										
1	9:53 AM	AMT 1	< 7	< 7	17.0	86	1.0	NW	87 000	Sunny
2	9:56 AM	AMT 2	< 7	< 7	17.0	77	1.0-2.0	NW	85 100	
3	10:12 AM	AMT 3	< 7	< 7	19.0	70	1.5-2.5	W	82 000	Light Cloud
4	nt	AMT 4	nt	nt	nt	nt	nt	nt	nt	
5	10:30 AM	AMT 5	< 7	< 7	19.0	70	3.0-7.0	WNW	70 000-110 000	Light Cloud
6	10:37 AM	AMT 6	< 7	< 7	17.5	73	3.0-5.0	WNW-W	50 000-100 000	Light Cloud
7	10:45 AM	AMT 7	< 7	< 7	17.5	73	2.0-3.5	N-W	91 000	
8	nt	AMT 8	nt	nt	nt	nt	nt	nt	nt	
9	11:20 AM	AMT 9	< 7	< 7	19.0	66	1.0-3.0	NW-W	98 000-100 000	
10	11:13 AM	AMT 10	< 7	< 7	19.5	66	1.0-5.0	N-W	92 000	
11	nt	AMT 11	nt	nt	nt	nt	nt	nt	nt	
12	10:52 AM	AMT 12	< 7	< 7	18.5	70	2.0-4.5	N-W	80 000-90 000	
Midday sampling run (11AM-2PM)										
1	12:50 PM	AOT 1	< 7	< 7	20.0	58	0.5-2.0	N-W	42 000-48 000	Cloud setting in
2	12:55 PM	AOT 2	< 7	< 7	19.5	58	1.0-2.0	W	41 000	
3	1:05 PM	AOT 3	< 7	< 7	19.5	58	2.0-4.0	W	41 800-44 200	
4	nt	AOT 4	nt	nt	nt	nt	nt	nt	nt	
5	1:10 PM	AOT 5	< 7	< 7	19.5	66	3.0-4.0	WNW	41 600	
6	1:15 PM	AOT 6	< 7	< 7	19.0	58	2.0-4.0	WNW	50 000-55 000	
7	1:25 PM	AOT 7	< 7	< 7	19.5	66	20.-4.0	W	54 000	Totally overcast
8	nt	AOT 8	nt	nt	nt	nt	nt	nt	nt	
9	1:05 PM	AOT 9	< 7	< 7	19.5	55	1.0-2.0	WNW	33 000	
10	1:30 PM	AOT 10	< 7	< 7	19.0	58	2.0-3.0	WNW	34 000	
11	nt	AOT 11	nt	nt	nt	nt	nt	nt	nt	
12	1:37 PM	AOT 12	< 7	< 7	19.0	58	1.5-2.5	NW	32 000	
Mid afternoon sampling run (2-4PM)										
1	2:45 PM	AAT 1	< 7	< 7	17.5	64	1.0-2.5	W	18 100	
2	2:50 PM	AAT 2	< 7	< 7	18.0	57	2.0-4.0	W	15 500	
3	2:55 PM	AAT 3	< 7	< 7	17.0	60	2.0-3.5	W	12 500	
4	nt	AAT 4	nt	nt	nt	nt	nt	nt	nt	
5	3:04 PM	AAT 5	< 7	< 7	17.0	65	4.0-7.0	WNW	12 900	
6	3:10 PM	AAT 6	< 7	< 7	17.0	65	3.0-6.0	WNW	12 800	
7	3:15 PM	AAT 7	< 7	< 7	17.0	60	2.5-4.0	WNW	15 500	Spitting
8	nt	AAT 8	nt	nt	nt	nt	nt	nt	nt	
9	3:48 PM	AAT 9	< 7	< 7	17.5	53	2.0-3.0	NW	20 500	Rain stopped
10	3:42 PM	AAT 10	< 7	< 7	16.5	64	1.0-2.0	W	13 500	
11	nt	AAT 11	nt	nt	nt	nt	nt	nt	nt	
12	3:20 PM	AAT 12	< 7	< 7	17.0	65	1.5-3.5	W	15 600	Spitting

RIVERSIDE GOLF COURSE MICROBIOLOGICAL DATASET

RESULT TABLE 4.3 - AEROSOL SAMPLE RESULTS (ROUND 3)

Control

Date: 26/3/96 — Previous 24 hrs rainfall: 0.0 mm — Weather conditions: Light cloud

			Microbiological results		Climatological results					
Site	Time taken	Sample Code	Faecal coliforms / m^3 *	*E. coli* / m^3 *	Air Temp. °C	Humidity (%)	Wind speed (m/s)	Wind direction	Light (lux)	Comments
Mid morning sampling run (9-11AM)										
1	9:15 AM	AMC 1	< 7	< 7	15.5	90	0.3	SE	29 500	Air sampler on rough
2	9:20 AM	AMC 2	< 7	< 7	17.0	87	0.0-0.5	E-NE	17 900	Air sampler on rough
3	9:30 AM	AMC 3	< 7	< 7	17.5	82	Calm	E	28 700	Air sampler on rough
4	nt	AMC 4	nt	nt	nt	nt	nt	nt	nt	
5	9:35 AM	AMC 5	< 7	< 7	17.0	90	1.0-2.0	E	25 700	Dew
6	9:45 AM	AMC 6	< 7	< 7	17.0	86	0.0-5.0	N	16 900	In shadow
7	10:25 AM	AMC 7	< 7	< 7	21.0	73	0.0-5.0	N	46 100	
8	nt	AMC 8	nt	nt	nt	nt	nt	nt	nt	
9	10:30 AM	AMC 9	< 7	< 7	21.0	77	1.0-4.0	NE	59 700	
10	9:55 AM	AMC 10	< 7	< 7	17.0	87	0.0-0.5	S-E	20 700	In shadow
11	nt	AMC 11	nt	nt	nt	nt	nt	nt	nt	
12	10:00 AM	AMC 12	< 7	< 7	18.5	83	0.5-4.5	N-E	45 000	Sunny
Midday sampling run (11AM-2PM)										
1	11:35 AM	AOC 1	< 7	< 7	20.5	73	0.0-0.5	N	19 000	Overcast
2	11:40 AM	AOC 2	< 7	< 7	21.0	73	0.0-0.5	SSE	18 500	
3	11:48 AM	AOC 3	< 7	< 7	21.5	73	0.0-0.5	NNW	29 700	Brightening
4	nt	AOC 4	nt	nt	nt	nt	nt	nt	nt	
5	11:55 AM	AOC 5	< 7	< 7	21.5	73	0.5-1.0	ENE	37 000	
6	12:00 PM	AOC 6	< 7	< 7	22.0	73	0.0-0.5	NE	38 000-48 000	Still cloudy
7	12:08 PM	AOC 7	< 7	< 7	22.0	73	1.5-2.5	SW	45 000-53 000	
8	nt	AOC 8	nt	nt	nt	nt	nt	nt	nt	
9	12:40 PM	AOC 9	< 7	< 7	22.5	71	0.5-2.0	E	16 200	
10	12:15 PM	AOC 10	< 7	< 7	22.5	74	1.5-2.5	SSE	48 000	
11	nt	AOC 11	nt	nt	nt	nt	nt	nt	nt	
12	12:20 PM	AOC 12	< 7	< 7	22.5	74	1.0-3.0	E-SE	35 000	
Mid afternoon sampling run (2-4PM)										
1	2:30 PM	AAC 1	< 7	< 7	24.5	63	2.0-4.0	ESE	74 800	Sunny
2	2:45 PM	AAC 2	< 7	< 7	24.5	63	1.0-2.0	E-SE	33 000	light cloud
3	2:50 PM	AAC 3	< 7	< 7	24.0	65	1.0-3.0	E	35 000	light cloud
4	nt	AAC 4	nt	nt	nt	nt	nt	nt	nt	
5	3:03 PM	AAC 5	< 7	< 7	23.5	58	3.0-6.0	E-SE	30 000	Wet bulb query
6	3:32 PM	AAC 6	< 7	< 7	23.5	68	2.5-4.0	SE	21 000	Cloudy
7	3:42 PM	AAC 7	< 7	< 7	23.0	71	1.5-4.0	E	21 500	Cloudy
8	nt	AAC 8	nt	nt	nt	nt	nt	nt	nt	
9	3:47 PM	AAC 9	< 7	< 7	23.0	71	1.5-3.0	SSE	22 500	Cloudy
10	3:11 PM	AAC 10	< 7	< 7	23.5	68	1.5-2.5	S-SE	24 000	Cloudy
11	nt	AAC 11	nt	nt	nt	nt	nt	nt	nt	
12	3:20 PM	AAC 12	< 7	< 7	23.5	68	2.0-4.5	SE	22 700	Cloudy

* 160 L converted to 1m^3

Effluent Affected

Date: 27/3/96 — Previous 24 hrs rainfall: 2.0 mm — Weather conditions: Sunny but hazy

Mid morning sampling run (9-11AM)										
1	9:30 AM	AMT 1	< 7	< 7	16.0	82	Calm	-	28 000	Sampler in rough
2	9:43 AM	AMT 2	< 7	< 7	15.0	90	Calm	-	37 000	Sampler in rough
3	9:50 AM	AMT 3	< 7	< 7	16.0	87	0.5-1.5	NE	42 000	Light Cloud
4	nt	AMT 4	nt	nt	nt	nt	nt	nt	nt	
5	9:55 AM	AMT 5	< 7	< 7	16.5	86	0.5-1.0	NE	39 000-42 000	Hazy
6	10:00 AM	AMT 6	< 7	< 7	15.5	90	Calm	-	28 000	Shady
7	10:10 AM	AMT 7	< 7	< 7	16.0	86	1.0	E	49 000	Sunny & light cloud
8	nt	AMT 8	nt	nt	nt	nt	nt	nt	nt	
9	10:15 AM	AMT 9	< 7	< 7	16.0	86	1.2-1.8	SE	23 000	Cloudy
10	10:40 AM	AMT 10	< 7	< 7	17.5	83	0.7	NNE	50 500	Almost sunny
11	nt	AMT 11	nt	nt	nt	nt	nt	nt	nt	
12	10:25 AM	AMT 12	< 7	< 7	16.5	86	0.5-1.5	ENE	54 300	Sunny but hazy
Midday sampling run (11AM-2PM)										
1	11:35 AM	AOT 1	< 7	< 7	19.5	83	0.5-2.0	N-NW	73 000	Grass still moist
2	11:45 AM	AOT 2	< 7	< 7	20.0	80	1.0-2.0	NW	70 500	Sunny
3	12:00 PM	AOT 3	< 7	< 7	20.0	80	0.5-1.5	NW	70 000	
4	nt	AOT 4	nt	nt	nt	nt	nt	nt	nt	
5	12:10 PM	AOT 5	< 7	< 7	21.0	77	1.0-5.0	NW	65 500	Sunny and hazy
6	12:20 PM	AOT 6	< 7	< 7	22.0	77	0.5-1.5	NW	71 500	Sunny and hazy
7	12:25 PM	AOT 7	< 7	< 7	22.0	73	1.5-2.5	NW	60 800	Grass almost dry
8	nt	AOT 8	nt	nt	nt	nt	nt	nt	nt	
9	12:50 PM	AOT 9	< 7	< 7	21.0	77	0.0-2.5	W-NW	60 000	
10	12:55 PM	AOT 10	< 7	< 7	21.5	77	1.5-4.0	N	52 000	
11	nt	AOT 11	nt	nt	nt	nt	nt	nt	nt	
12	12:35 PM	AOT 12	< 7	< 7	21.5	74	1.5-3.5	NW	65 300	
Mid afternoon sampling run (2-4PM)										
1	2:10 PM	AAT 1	< 7	< 7	22.5	74	0.5-1.5	N-NW	73 000	Clear but hazy
2	2:20 PM	AAT 2	< 7	< 7	23.5	74	0.5-1.0	NW	70 500	Grass dry but damp underneath
3	2:30 PM	AAT 3	< 7	< 7	23.5	74	0.5-2.5	NW	70 000	
4	nt	AAT 4	nt	nt	nt	nt	nt	nt	nt	
5	2:35 PM	AAT 5	< 7	< 7	23.5	68	1.0-5.0	NW	65 500	
6	2:42 PM	AAT 6	< 7	< 7	23.5	68	0.5-1.5	NW	71 500	
7	3:20 PM	AAT 7	< 7	< 7	23.5	72	1.5-2.5	NW	60 800	Spitting
8	nt	AAT 8	nt	nt	nt	nt	nt	nt	nt	
9	3:10 PM	AAT 9	< 7	< 7	23.0	72	0.0-2.5	W-NW	60 000	Rain stopped
10	3:05 PM	AAT 10	< 7	< 7	23.5	72	1.5-4.0	N	52 000	
11	nt	AAT 11	nt	nt	nt	nt	nt	nt	nt	
12	2:50 PM	AAT 12	< 7	< 7	23.5	68	1.5-3.5	NW	65 300	Spitting

CHAPTER 8

DISCUSSION

8.1 Introduction

The format of this section essentially presents each point in order of relevant importance particularly in regards to the hypothesis that the reduction of the occurrence and prevalence of faecal contamination throughout the golf course is sufficient to not present an undue health risk to golfers and course personnel. Hence the potential pathways of the highest risk of infection will be discussed first, then followed by the pathways of lesser risk. Discussion will initially focus on the microbiological findings in the STP effluent followed by that found in the holding pond, the turfgrass, players' hands and golf balls, the irrigant water, the aerosols, soils and the creek. A couple examples of a probabilistic health risk assessment of two pathogens that may be present in domestic sewage or in wildlife are performed to provide additional evidence of the potential risks involved. Finally, some cautionary notes will be made before some final conclusions and implications are stated.

Past research has shown that pathogen survival is enhanced by low temperatures, moist conditions and an absence of UV irradiation (Gerba et al. 1975; Sagik et al. 1978). The weather patterns over the 1995/96 irrigation season displayed both below average temperatures and above average rainfall. In this regard, this season served well as a worst case scenario. Although, as a consequence of the higher rainfalls the actual irrigant applied, in particular to the fairways, was considerably less than normal thus counteracting the increase risks due to the weather favouring pathogen survival.

Despite the relative increase in temperature from beginning to end of the irrigation season there appears to be no noticeable corresponding decrease in bacterial levels in the environmental samples collected from round to round.

8.2 Sewage Treatment Plant Effluent

The sample results for all sampling rounds indicates the effluent is treated to a high quality. Only one sample exceeded the DELM, 1994, *Guidelines for Re-use of Wastewater in Tasmania*, 5 000 FC/100 mL maximum allowable of limit from 5 samples taken at

half hourly intervals with an allowable geometric mean of 750 FC/100 mL for restricted public access reuse. The undetectable counts for Round 2 is attributed to a sufficient dose of STP chlorine disinfection at the time to kill essentially all faecal coliforms. Nothing unusual in terms of effluent pH, conductivity and temperature would have caused such low numbers to occur. Thus the quality of the effluent reaching the holding pond is quite microbiologically clean and consistent.

8.3 Holding Pond

The counts were considerably higher than the levels found in the STP effluent and are well above the mean FC levels of 750 FC/100 mL cited in the DELM (1994: 11) guidelines and the National Water Quality Management Strategy guideline (NHMRC et al. 1996: 8, 24) median value of 1 000 thermotolerant coliforms/100 mL for controlled public access municipal/urban greenspace irrigation. This increase is attributed to the water fowl frequenting the pond and defaecating in it (Plate 5.8).

The levels of FC/*E. coli* found in the fenced holding pond were consistently the highest of all the environmental samples collected and thus present the highest hazard to golfers and groundstaff. Yet it is unlikely to present a high risk to them since they are not in the regular habit of directly coming into contact with it. In particular, the pond bottom sediment appears to have highly concentrated levels of faecal pollution as indicated by the high Round 1 sample of 10 300 cfu/100 mL which resulted from disturbing the pond sediment whilst sampling. This count is attributed to excrement deposited by water fowl that settles to the bottom of the pond.

Dr. Gary Grohmann (Veterinary Pathology, University of Sydney, 1996, pers. comm., 12 June) indicated that water fowl will carry the protozoa pathogens, *Giardia* and *Cryptosporidium*, although *Cryptosporidium* has been detected in lower numbers. Other organisms possibly present are the influenza virus and bacterial pathogens like *Salmonella* although their environmental survival is limited. Enteric virus transmission via water fowl is unlikely. Importantly, dosages of protozoa to cause an infection are orders of magnitude lower than for bacteria and these organisms exhibit better survival in the environment and increased resistance to disinfection.

8.4 Turfgrass

The hazard that presents the highest risk is the turfgrass on the morning after it is irrigated because it contains the highest levels of faecal contamination that golfers and

groundstaff will have contact with on a regular basis. The irrigant itself although presenting the second highest hazard is not a high risk for irrigation takes place at night when golfers or groundstaff are not present. The sprinkler system ceases operation 2-3 h before play begins.

Unfortunately, no inter-round comparison can be made with the turfgrass samples since an adequate sampling and analysis method was not developed until Round 3. Nevertheless, sites 9 & 10 which gave detectable readings in Round 2 have been sites where specific conditions have supported FC/*E. coli* survival. Site 10 throughout the sampling program has had unusually high soil moisture characteristics, 174%-192%.

One major difficulty in monitoring the presence of FC/*E. coli* on the turfgrass introduced by effluent irrigation is distinguishing between FC/*E. coli* possibly introduced by wildlife frequenting the test area (external contamination) and that introduced by the irrigant itself. The faecal matter in the control samples may be a product of both external contamination and past irrigation events as illustrated by Figure 8.1, whereby FC/*E. coli* settles among the grass roots and stems away from the harmful affects of UV, desiccation and soil predators. The previous irrigation events occurred 3 days prior for the greens (40 min application) and 4 days prior for the fairways (10 min application) which are within the 15 day survival limit for faecal coliforms on crops at 20-30°C (Feachem et al. 1983). In addition, the effluent-affected sample results are also a product of external contamination and irrigation.

To account for contamination from sources other than irrigation the following observations and assumptions were made:

- External (wildlife) contamination on the turfgrass occurs due to the presence of birdlife, rabbits and marsupials;
- When sampling, obvious scats (faeces) were avoided;
- Regular mowing (every 2-3 days for fairways and every 1-2 for the greens) would tend to scatter the faeces and make their distribution on the fairways and greens much more uniform; and
- No surface water introduced by irrigation was present that would attract wildlife to a particular site.

From these observations and assumptions, it is assumed that the contribution by wildlife is similar before and after irrigation.

Nevertheless, from a public health point of view the total amount of FC/*E. coli*, whatever the source, is the essential concern because one cannot ignore that wildlife frequenting the golf course may also be considered as potential carriers of enteric disease (Robinson 1996, 30–32).

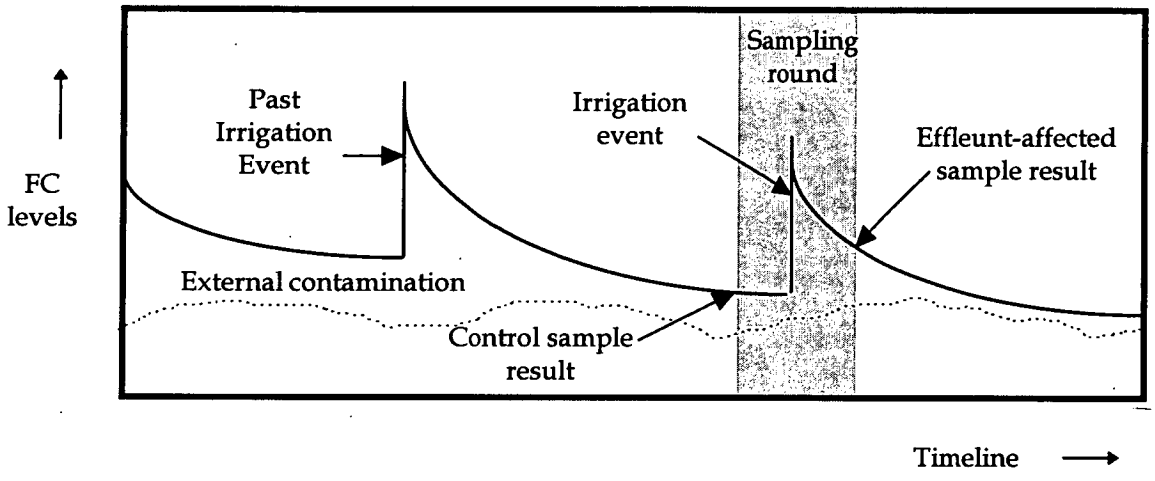

FIGURE 8.1 - Predicted variation of faecal coliform concentrations in the turfgrass during the irrigation season

For Round 3 control samples, an almost 2 orders of magnitude difference in FC levels between sites can either be explained by sporadic wildlife contamination, site specific factors that affect long term FC survival, or heterogeneity of effluent combined with different application rates applied during the last irrigation event. A similar variation in the effluent-affected results between sites occurs (66–13 000 cfu/100 mL eq.). One would expect some of this variation would be due to the heterogeneity in the irrigant as indicated by the irrigant result range of 500–7 300 cfu/100 mL and also due to the different amounts of irrigant applied to each site (Result Table 2.2). Nevertheless, there does not appear to be any correlation between these three parameters (Figure 8.2). The high effluent-affected turfgrass results at site 1 & 12 indicate either recent external contamination or heavily contaminated particles were picked up by the inlet of the irrigation pump.

Effluent-affected samples were collected before mowing so that any additional external contribution occurring during the night would be minimised. Therefore the difference

between the control and effluent-affected sample results is likely to be due to the effect of irrigation alone.

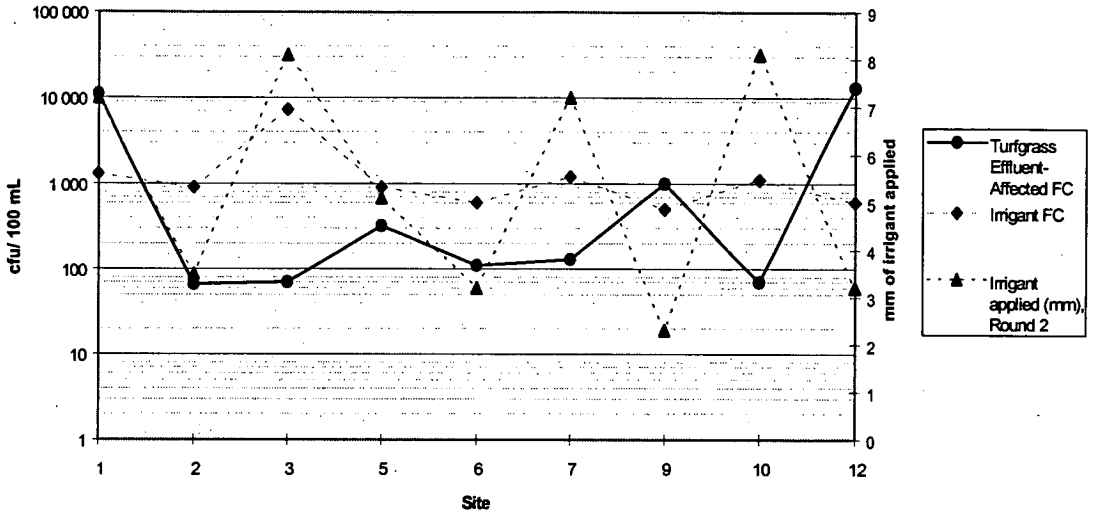

FIGURE 8.2 - Correlation between turfgrass FC/*E. coli* (effluent-affected) with volume and FC/*E. coli* concentration of irrigant applied between sites

The t-test confirmed a significant increase in the difference before and after irrigation. Comparing the means of the control and effluent-affected samples gives an idea of the difference, 75 cfu/100 mL compared with 391 cfu/100 mL respectively. Figure 8.3 also illustrates the difference between before and after irrigation. The majority of data points are placed above the 45° line indicating higher values after irrigation than before. This difference is attributed to the levels of FC/*E. coli* in the irrigant that was applied to the test area.

The mean of the effluent-affected samples is still below the recommended guideline limit of 750 cfu/100mL for restricted access irrigation DELM (1994) guidelines. Nevertheless this limit is only applicable to the effluent leaving the sewage treatment plant. Interestingly, the ANZECC, 1993, *Australian Water Quality Guidelines for Fresh and Marine Waters*, which is a more appropriate guideline level for personal contact with the effluent, stress a much more liberal median limit of only 1 000 faecal coliform/100 mL from a minimum of five samples taken at regular intervals not exceeding one month for secondary contact (such as that which would occur for boating, wading or fishing). The median level of 120 cfu/100 mL for the effluent-affected samples is well below this limit.

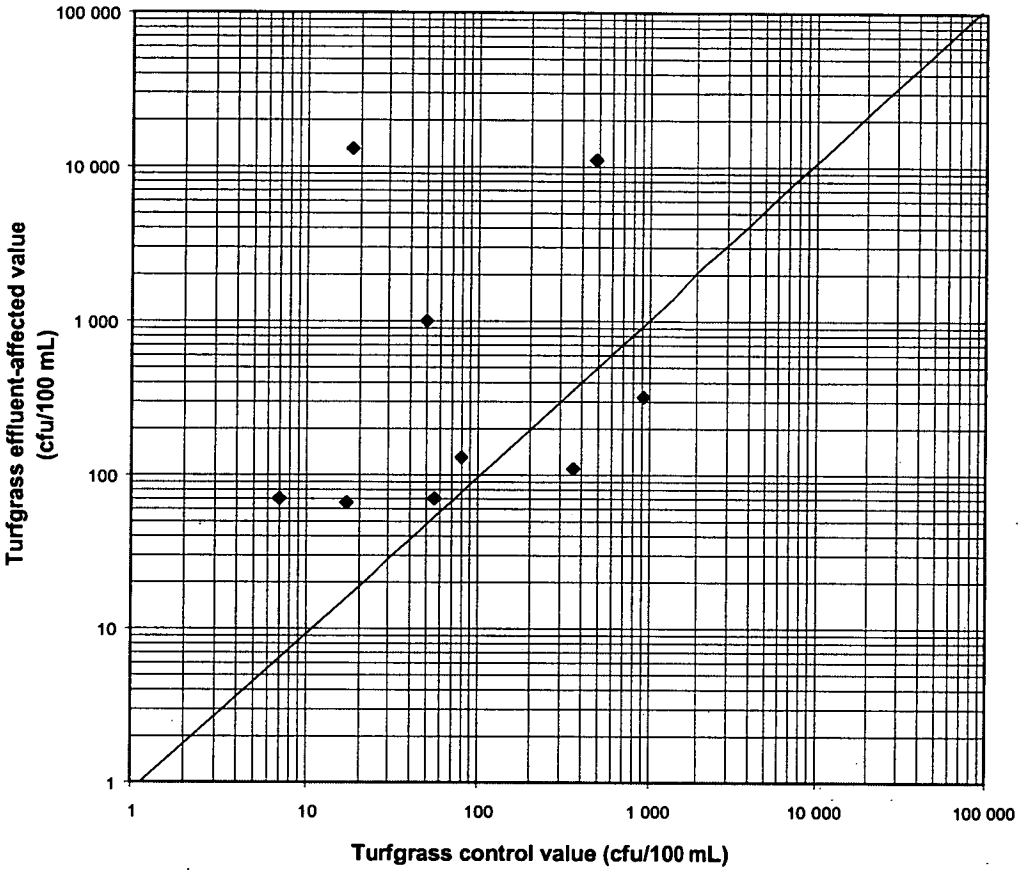

FIGURE 8.3 - Paired comparison between control and effluent-affected turfgrass *E. coli* results (Round 3)

Comparing the effluent-affected irrigant samples with the turfgrass effluent-affected sample results, the t-test 95% confidence interval indicates no significant difference. Nevertheless, only two sets of nine samples were used to make these conclusions. Preferably, more samples need to be taken to provide greater robustness in the statistical analysis. Considering the 3 fold difference between the means, 1 069 cfu/100 mL for the irrigant and 391 cfu/100 mL for the turfgrass, other factors provide a reason for this difference. Firstly, the turfgrass was considerably wet already after rainfall occurred before irrigation diluting the turfgrass FC/*E. coli* concentrations by 1.25 to 1.90 times. This factor almost accounts for a 3 fold difference in the means. Secondly, the presence of endemic soil predators in the turfgrass combined with the possible lack of nutrients on the grass could promote a reduction FC numbers. Desiccation or UV irradiation would not be influential factors since the grass was quite wet and the sun had not risen when the samples were collected. Figure 8.4 also shows a tendency for turfgrass FC/*E. coli* to be less than the corresponding irrigant FC/*E. coli* level at each site.

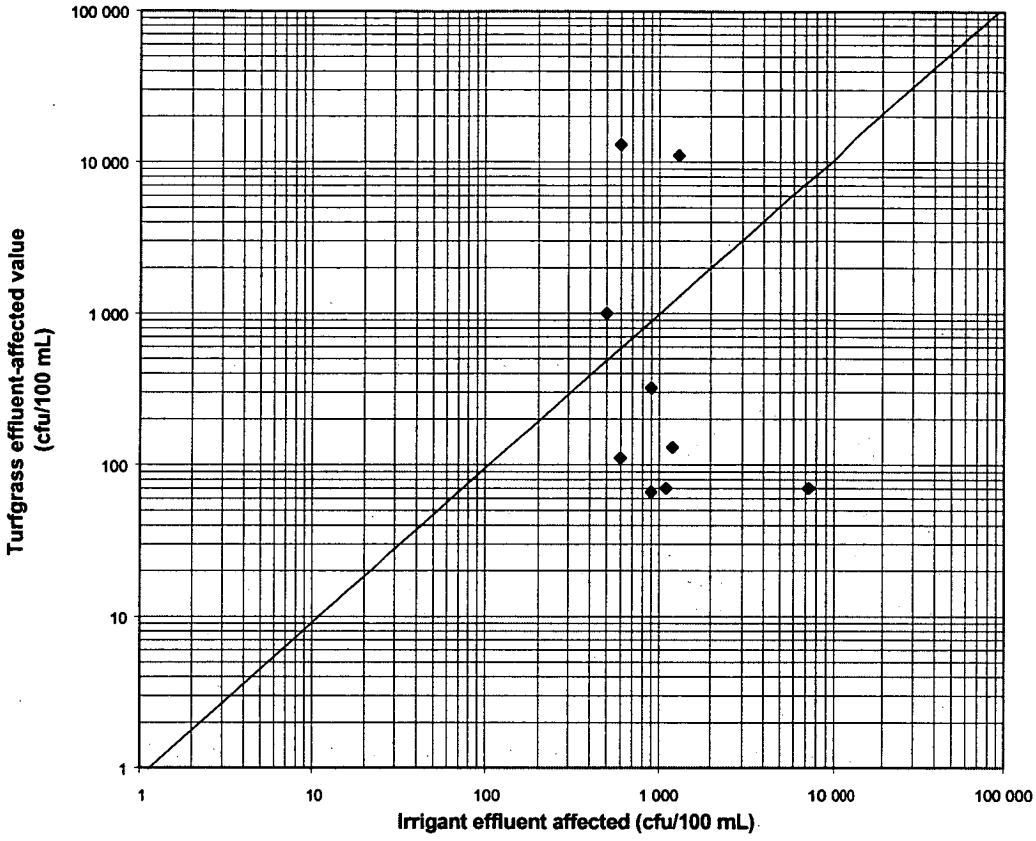

FIGURE 8.4 - Paired comparison between irrigant (effluent-affected) and turfgrass (effluent-affected) FC/*E. coli* Results (Round 3)

A rate of reduction in FC/*E. coli* on the turfgrass can be estimated by comparing the FC/*E. coli* mean of the turfgrass samples (616 cfu/100 mL eq. adjusted to eliminate the affect of overnight rainfall) with the original holding pond mean level (2 110 cfu/100 mL) for Round 3. The adjusted figure is used as a worst case scenario, that is, no rain to dilute the irrigant. This represents a reduction of the irrigant concentration of 3.43 times {0.535 log reduction, i.e. log (2 110) - log (616)} over an average 7.5 h period during the night of irrigation under the specific environmental conditions of no light, cool temperatures and high moisture between a 3 to 12 hour period. This would approximately equate to an hourly dieoff rate of 0.535/7.5 = 0.071 log reduction/h, that is, a 15% reduction of FC/*E. coli* per hour on turfgrass once the irrigant has been deposited when the initial effluent concentration mean is 2 110 cfu/mL. Using the DELM withholding period of 4 h this would give a turfgrass FC concentration of 2 110 x $(1.0 - 0.15)^4$ = 1 100 cfu/100 mL which does exceed the ANZECC (1992) secondary contact guidelines.

Nevertheless, this reduction is not necessarily continuous for an initial 'aerosol shock' observed in other studies (Schaub et al. 1978; Biederbeck 1979) would significantly reduce numbers during irrigation. Aerosol shock is inferred from the t-test performed in the Results section that compared the means for all rounds of the holding pond sample results and the effluent-affected irrigant sample results assuming FC dieoff in the irrigant containers is minimal before sampling. The initial turfgrass FC values just after it is applied to the turfgrass would more closely match the irrigant FC mean value of 1 070 cfu/100 mL for Round 3. Using this value as the starting value then gives a dieoff rate of {log (1 070) - log (616)}/7.5 = 0.032 log reduction/h (7.1% reduction/h). This reduction occurring over 4 h gives a final mean turfgrass value of 800 cfu/100 mL before the start of play which is a little higher than the sample result value of 616 cfu/100 mL and under the ANZECC (1992) secondary contact guideline. Nevertheless, it must be borne in mind that this calculated dieoff rate is based on only 3 holding pond samples and 9 turfgrass samples. Many more would need to be collected and analysed before making any firm predictions of FC/*E. coli* reduction under similar conditions.

In regards to the amounts of effluent applied over the irrigation season, the tees and greens were irrigated approximately six times more frequently than the fairways. Also the green turfgrass rootlets were quite thick and dense compared with the fairway turfgrass enabling a safe habitat for FC and other microbes. This would contribute to a greater concentration of faecal bacteria in the green turfgrass than in the fairway turfgrass. A comparison in the mean FC result tends to confirm this: 735 cfu/100 mL eq. and 236 cfu/100 mL eq. for green and fairway turfgrass respectively (both these figures are not adjusted for the overnight rain). This makes contact with the tees and greens more hazardous than contact with the fairways. In addition, from observing the players' behaviour, the level of risk is higher on the greens and tees more than on the fairways since hand contact with the tees and greens turfgrass is noticeably more prevalent than with the fairway turfgrass (this is discussed further in the following section on golf balls and players' hands).

Nevertheless, whatever the source of contamination, there is a substantial reduction in FC/*E. coli* numbers in both types of turfgrass by the time daylight arrives that leaves little to contaminate players and groundstaff. All the sampling round results confirm this because extremely little trace of FC/*E. coli* was found on golf balls or on players' hands.

8.5 Golf Balls and Players' Hands

Despite the potential of these pathways being a high risk for infection, FC/*E. coli* levels were consistently undetected or several orders of magnitude less than the required dosages to cause an infection, at least in the case of bacterial infections. Only one player of 29 sampled had a positive count of 1 cfu/100 cm^2 on the hand after irrigation for all sampling rounds and only 3 positive counts (all $\leq$ 4 cfu/50 cm^2) of 29 golf balls sampled were recorded.

To understand why very little faecal contamination was detected on the golf ball samples, consideration needs to be made of the kinetics which the golf ball undergoes during play that will affect the adsorption and desorption of faecal bacteria from the ball. Firstly, during teeing off, impact loads on the ball are extreme. Some of the bacteria picked up from the last hole played may either be killed or expelled from the ball to some extent, due to the severe impact and resulting shock waves thus reducing their numbers. When the ball first lands on the turfgrass, compression into the turfgrass may allow adsorption of bacteria whilst others are desorbed. As the ball continues to bounce and roll along the turfgrass, more will adsorb and/or desorb due to skidding and rolling action of the ball. Successive shots will continue this process of desorption and adsorption until an equilibrium number of bacteria is reached. On the greens, with the lighter shock loads of chipping and putting, resulting in a rolling rather than a skidding action, together with proportionately higher counts on the greens, there exists a greater potential for bacterial adsorption. Teeing off at the next hole will again reduce numbers. Significantly, between the predicted highest acts of adsorption and desorption, players have the most contact with their golf balls therefore accentuating potential pathogen transfer from ball to hands. This pathogen transfer would be cumulative from hole to hole since no particular behaviour of the golfer would ensure their removal until the end of their round. Yet in spite of this cumulative effect, insignificant FC/*E. coli* were detected on their hands.

8.6 Irrigant Water

The cause of the slight variation in the FC/*E. coli* counts in the irrigant water between sites is likely to be due to two things. One, the non-homogeneity of FC/*E. coli* levels in the holding pond itself due to the activity of the birdlife and the intermittent resuspension of the heavily contaminated sediment. Each irrigant sample was a 15 min composite, a relatively short period compared with the overall irrigation time. With the activity of birdlife in the pond and the dropping level of the pond during

irrigation, disturbance of the sediment and suspended particles could well vary every quarter hour resulting in different concentrations at each site. This heterogeneity was confirmed by the high Round 1 sample of 10 300 cfu/100 mL which resulted from disturbing the pond sediment whilst sampling. Two, each site was irrigated at different times during the night resulting in differing stages of FC/*E. coli* dieoff. Because of the cool, dark conditions, significant natural dieoff of the FC/*E. coli* in the irrigant is unlikely.

There is a noticeable difference between the means for each round. In Round 2, slightly lower counts occurred compared with the other two rounds. In addition, the pre-irrigation season samples were quite low. Explanation for this is not yet apparent although one possible reason is the diluting effect of filling up the pond with more microbiologically clean STP effluent over a period of time due to the high irrigation demand in the period before Round 2 (Appendix 6). Another reason is the apparent heterogeneity of the distribution of organic matter in the holding pond.

The difference in the means between all the holding pond sample results and the irrigant sample results indicate a reduction in the vicinity of 900 cfu/100 mL. The t-test result was borderline. Natural dieoff at night with temperatures between 5.5–10.5°C is an unlikely cause. The other likely option is dieoff due to aerosol shock as previously mentioned. If aerosol shock can be inferred, dieoff due to its affects is in the order of a 0.29 log reduction (51% reduction).

The positive result for the control sample at site 9 for Round 2 probably resulted from external contamination or alternatively, irrigation actually took place on the 9th green.

8.7 Aerosols

Again the control and effluent-affected aerosol sampling for all rounds produced practically no counts. A total of 180 aerosol samples were collected and only one positive count of 2 cfu/160 L (13/m^3) was detected. Therefore one can safely say the risk to the players of pathogen inhalation due to wastewater irrigation overnight is extremely low. An individual who plays a 3 h round of golf involving a moderate breathing rate of 1 m^3/h (Masters 1991: 207) will inhale 3 m^3. For the highest count observed of 13 FC/m^3 this would amount to a total dose of about 40 FC. *Salmonella* which is also a bacterium and can be transmitted by water fowl as well as be aerosolised because it is light, requires a dose of 10^5–10^8 organisms (Bryan 1977) to

initiate an illness in less than 25% of people exposed. So the likelihood of infection via this route is remote.

The reason for the absence of FC counts in the morning of Round 1 after irrigation was likely to be due to the air being quite calm. Wind speed varied from 0 to 2.5 m/s, making it unlikely that irrigant water droplets or particles would be aerosolised. The meteorological parameters of high light readings throughout the day, 16 000–108 000 lx, and relatively low humidity, 52%–78%, with higher wind speeds later in the day after irrigation, would also respectively kill and desiccate airborne microbes quite quickly. These factors tend to explain the very low FC/*E. coli* results.

Likely causes for non detection for Rounds 2 & 3 were the prevailing meteorological conditions. For Round 2, air temperature varied between 17.0–20.0°C, humidity, 58%–77%, wind speed, 1.0–7.0 m/s and sunlight, 13 500–110 000 lx. The conditions of low humidity, warm temperatures and bright sunlight would minimise the short term survival of aerosolised bacteria. In regard to wind speed, although high wind speeds of 7.0 m/s were recorded, wind speeds above 4.0 m/s tended to be short gusts not sustained for long periods and occurred mainly in the afternoon when the turfgrass was usually dry (attempts were made to measure the surface moisture quantity on the turfgrass but proved unsuccessful). Thus aerosolisation, particularly from early morning dew, when wind conditions were the calmest would be minimal. Relatively calm conditions also during Round 3, where wind speed ranged from calm to 5.0 m/s winds and averaging around 1.5 m/s after irrigation could explain non detection of bacterial aerosols.

It is also important to note that the typical air sampler efficiency of collection for different sized particles for the type of centrifugal air sampler used are as follows (Macher & First 1983):

12 μm	80–100%
4–6 μm	55–77%
2 μm	5–7%
<1 μm	<1%

One *E. coli* bacterium typically measures 0.5 × 2 μm (Metcalf & Eddy 1991: 90). So a single *E. coli* can easily miss detection. Therefore only particle-associated clusters of *E. coli* can be detected. This should not be of much concern, for it was observed that the effluent was quite turbid, ranging between 29–62 FTU (67–150 mg/L SS) for Rounds 2

& 3 (Results Table 1.2 & 1.3), indicating a substantial amount of particulate matter with which bacteria will tend to associate. In addition, bacteria tend to dwell in microcolonies. Therefore, sample results indicate essentially no counts of *E. coli* and almost no counts of faecal coliforms.

8.8 Soils

The soil presents little risk to golfers and groundstaff because of the low occurrence of regular human contact and the lower levels of faecal bacteria found compared with the levels in the turfgrass. Typically, the presence of FC/*E. coli* tends to be vary sporadic, that is, most of the sites will have no detectable amounts whilst the sites that do may vary from 10 - 500 FC/g for all rounds.

A possible reason for the lack of microbial counts in the soil samples for the majority of the sample sites after irrigation in Rounds 1 & 2 was the irrigation practice of the golf course. Little, if any, of the irrigant reached the soil since the application period was usually not long enough (8 - 60 min for greens, 10 - 15 min for fairways). Notably, from the soil moisture t-test comparison, no significant increase in soil moisture took place after irrigation for all rounds. The root system of the grass was quite dense ensuring that most of the effluent was taken up by the turfgrass before it reached the topsoil. This is particularly so with the green turfgrass. With the appointment of a new course superintendent in January, 1996, longer irrigation applications took place (30 - 60 min for greens, 10 - 30 min for fairways). This would encourage faecal coliform migration into the topsoil. For Round 3, only sites 2, 6 & 12 had undetectable amounts of FC. Only *Enterobacter, Klebsiella* or *Citrobacter* were detected and not *E. coli*. The reason for this is probably their better adaptation to soil as a habitat.

The presence of FC/*E. coli* appears to be associated with two factors: high soil moisture content, especially over 100%, and high irrigant applications. For Round 1, only the greens had been previously irrigated for the season (Appendix 6). Therefore, the likely cause of the four positive counts recorded is direct recent contamination by wildlife combined with mowing and recent rainfall which would allow seepage of scattered faeces into the topsoil. The most apparent explanation for the increased occurrence in FC in Round 3 compared with the other rounds is the previous 20 or so days intense irrigation (particularly on the greens) supplemented by a high rainfall event which would assist migration into the topsoil.

For all rounds, site 10 had three high counts of 100, 200 & 500 FC/g and site 7 had two counts of 150 and 200 FC/g. Consistently high levels of soil moisture occurred at both sites, allowing for the migration and longer term survival of FC/*E. coli* as it passed into the soil column. High moisture content at site 10 resulted from the nearest sprinkler over irrigating the site due to the timer being incorrectly set and a nearby leaking irrigation main which was being repaired during Round 2. FC/*E. coli* can survive several days and sometimes weeks in the soil environment. Feachem et al. (1978, 1983), Kowal et al. (1981) and Bryan (1977) estimated that FC can survive in soil usually up to 20 d at 20 - 30°C. Clay soils with high organic content also provide a nutrient supply for bacteria (Killham 1994: 2). Site 3 also had two positive counts. Sites 3, 7 & 10 received the highest levels of irrigant, 7.2 - 8.1 mm for Round 2, and thus received the highest loading of bacteria.

There is a significant decrease in soil moisture content from Round 1 to Round 3 despite the very heavy rains in January. These results, plus the absence of detectable FC/*E. coli* in the soil for Round 2 despite fairly intense irrigation of the greens, again support the conclusion that little faecal matter percolates down into the topsoil. The measured soil pH, temperature, conductivity and moisture levels do not appear to be hostile to the survival of the bacteria.

Site 9 moisture content was low and therefore it is not easily apparent why it consistently had high levels of FC contamination. One possible explanation is that this is the closest site to a duck colony and ducks were observed on one occasion visiting this site, thus making an increased contribution to the presence of faecal coliforms.

8.9 Creek Water

Little can be ascertained from the creek samples due to the lack of samples taken for the last two rounds. At the beginning of the irrigation season almost no sign of faecal contamination was detected whereas, for two samples at the end of the irrigation season, the counts were relatively high. The possible reason for low counts in Round 1 was the creek water conductivity levels being quite high, 1 250 - 4 630 μS/cm and the pH readings being very low, 2.6<pH<3.9. These two factors, together with sunny conditions and shallow clear water make hostile conditions for FC/*E. coli* to survive. In regards to the reasons for the relatively high counts in the pond on the 7th hole for Round 3, the presence of birdlife defecating in the pond may have produced these

levels. Irrigant is able to reach the pond yet such small amounts are applied such that significant increases in FC/*E. coli* levels are unlikely to be due to irrigation alone.

8.10 Sample Health Risk Assessment

To provide an indication of the likelihood of an infection occurring through a golfer ingesting a particular bacterial pathogen found on the hands, the following two example calculations are presented:

Using *Salmonella* as a pathogen likely to be present, the dose response model is a beta-distribution model (Rose & Gerba 1991a: 30-31):

$$P = 1 - \left(1 + \frac{N}{\beta}\right)^{-\alpha}$$ where P is the probability of infection, N is the number of organisms ingested, $\alpha = 0.33$ & $\beta = 139.9$.

For N, the maximum concentration found on a player's hand will be used for *Salmonella*, which was 1 cfu/100 cm^2 organism ingested for each round of golf by putting ones hand to the mouth. The probability of infection becomes,

$$P = 1 - \left(1 + \frac{6.16}{139.9}\right)^{-0.33} = 0.0023$$

The yearly probability of infection if a golfer plays twice a week throughout the 6 month irrigation season (which amounts to 48 days of golf) is:

$$P = 1 - (1 - 0.0023)^{48} = 0.104$$

This risk is quite high, that is, a 1 in 10 chance of an infection, although this still may not result in an illness. Therefore, monitoring levels of *Salmonella* in the holding pond may be necessary from time to time. Stewart (1990), and Rose and Gerba (1991b: 2094) also provided figures for *Giardia* levels in chlorinated secondary effluent in the United States of 6 480–109 500 cysts/L and 48 cysts/40 L respectively. Its presence in this type of effluent is highly variable. Assuming a golfer ingests 1 mL of effluent during a day's play with a *Giardia* concentration/L based on the geometric mean of 948 cyst/L

based on the above figures, the probability of infection using the exponential dose-response model is:

$$P = 1 - e^{-Nr} = 1 - e^{-(948 / 1000 \times 0.02)} = 0.019$$

for a year's play the probability of infection becomes,

$$P = 1 - (1 - 0.019)^{48} = 0.60$$

Again, this risk is quite high, although *Giardia,* like most pathogens, have a 'boom-bust' life cycle and are unlikely to always occur at these high levels. Nevertheless, these two risk assessment examples based on pathogens that exist in water fowl would necessitate investigating the actual levels of these pathogens in the holding pond so that a more accurate risk assessment can be made.

Several cautionary notes, therefore, need to be made before one can confidently conclude that this method of reuse is 'safe'.

Firstly, pathogens other than bacteria usually have lower dose rates than bacteria in order to initiate an infection as illustrated by the above examples. That is, smaller population numbers of pathogens are required (Bryan 1977; Rose & Gerba 1991a: 31).

Secondly, not all possible pathways of infection were monitored in this experiment due to time and financial constraints. Of note, most aerosolisation studies are conducted when spray irrigation is taking place (Schaub et al. 1978; Avnimelech 1993; Teltsch and Katzenelson 1978). Since irrigation occurs at night when no one is on the course, the risks to players and staff are not present. Nevertheless, it was observed that some sprinklers were adjacent to or substantially within the DELM (1994: 13) recommended 100 m distance between the edge of the wetted area of the sprinklers and the nearest offsite dwelling. Of note, sprinklers on the 2nd tee and particularly the 15th tee and the 13th fairway, where the prevailing winds are north-westerly, are within these limits. To avoid spray drift into neighbouring residences, barriers, such as trees with dense foliage, can be employed. If a barrier is not provided, spray can enter these residences and contaminate washing hung out to dry or householders present in the garden.

Thirdly, the presence of faecal coliforms does not mandate the presence of pathogens or vice versa (Yates 1994: 15 and Marzouk et al. 1979). Therefore one must be cautious in making conclusions that a reuse practice is safe just because faecal coliforms occur below guideline values.

One factor in favour of the relative safety of a reuse scheme like this is the general high standard of health and hygiene that would typically exist in an urban development like Riverside. As a result, any bouts of an epidemic may be acute but most likely short lived compared to a stressed population. Nevertheless, no anecdotal evidence of any suspicious disease outbreaks occurring over the three years of operation of the reuse scheme was provided by the golfers when questioned.

Good hygiene can be a double edge sword whereby a lack of pathogen presence can lead to poor natural immunity within the community. Thus for concerned members, immunisation against some of the more virulent pathogens, such as, Hepatitis may be an option.

CHAPTER 9

CONCLUSION

9.1 Conclusion of the Riverside Golf Course Case Study

Fairly rapid dieoff of FC/*E. coli* on the turfgrass during the night, occurred after effluent irrigation. This was confirmed by extremely minimal detection of FC/*E. coli* on players' hands, golf balls and aerosolised bacteria despite the fact that the holding pond faecal bacteria concentrations exceeded the Tasmanian DELM's (1994) *Guidelines for Re-use of Wastewater in Tasmania* mean limit. From these results it is concluded that, on average, pathogen levels and their associated risks are very low.

The mean level of effluent affected turfgrass faecal coliforms before the day's play of 391 cfu/100 mL (or 616 adjusted for rain dilution) is less than the DELM (1994) and NH&MRC et al. (1996) limits of 750 and 1 000 cfu/100 mL respectively. Nevertheless, the faecal contamination in the irrigant itself was greater than or equal to this limit. This would necessitate a substantial withholding period. The rate of FC/*E. coli* dieoff after it is applied to turfgrass tends to confirm the sufficiency of the DELM guideline public withholding period of 4 hours.

Therefore, in conclusion, it would appear that the risks of infection due to this practice of effluent reuse are negligible. Nevertheless, water fowl can be carriers of disease that infect humans. Therefore, the activities of the waterfowl in the holding pond need to be considered as an alternative pathway of infection.

9.2 Recommendations to Enhance Public Health Protection on the Golf Course

It is recommended that samples of the holding pond water and sediment be monitored for the presence of pathogens, such as *Salmonella, Giardia* and *Cryptosporidium*, to obtain a more accurate assessment of the risks involved. If the risks are considered to be unacceptable, two options are recommended: removal of the water fowl or placement of a barrier around the holding pond that effectively keeps out the fowl.

Finally, as a precautionary measure, golfers and groundstaff should be encouraged to thoroughly wash their hands and golf balls after a round of golf or after completion of work before eating and drinking. Steps should also be made to cover drinking fountains located on the golf course to avoid contaminated aerosols from being

deposited on them. Finally, more adequate steps should be taken to protect neighbouring residences from overnight spray drift resulting from spray irrigation where the wetted areas are less than 100 m from neighbouring dwellings.

9.3 Future Directions for Wastewater Reuse in Temperature Australia

From the review of Australian wastewater reuse practices and trends (Chapter 3), it would appear that reuse schemes are widely practiced throughout the country and are steadily growing in number. In particular, agricultural and greenspace irrigation are the most popular forms of reuse. Greenspace irrigation of recreational areas, such as, golf courses, sports grounds, public parks and gardens will include a measure of public contact. Of particular concern is the possibility of the more susceptible younger, older and immunocompromised members of the community being exposed to any pathogens in the effluent.

The effluent used for these schemes tends to receive secondary treatment and chlorination. From Chapter 4, it is apparent that this is effective in significant reduction of bacterial pathogens, although other pathogens such as viruses, protozoa and helminths are able to survive treatment and persist longer in the environment and need fewer numbers in order to incite an infection. Kowal (1981: 329) comments that since there is a possibility of humans picking up an infection due to wastewater irrigation and therefore it is prudent to minimise the level of contact with the wastewater. In particular, untreated wastewater should never be used for irrigation in publicly accessible spaces.

With the increased potential of public exposure to these pathogens as the number of schemes increases, the risks of infection, although reportedly small, will likewise increase. Although no reported epidemics have clearly implicated this practice as being a pathway for disease transmission, the potential risk does exist. How great this risk is has not been determined from field measurements.

Another compounding factor, as highlighted by the case study, is the alternative vector of disease transmission due to the wildlife that inhabit TSE storage dams. Essentially it is raw water that receives no further treatment before it is utilised. If the sludge is disturbed during irrigation, quite significant numbers of microorganisms will be

deposited on the grass. People playing on the grass or young children eating it may present a high risk of infection.

Therefore, there is a need to monitor effluent quality from these storage facilities for the pathogen of concern rather than relying on indicator bacteria or monitoring the effluent that enters the storage dams. Gerba et al. (1996: 257) recommends that major efforts be made towards investigating the fate of microbial pathogens as greater exposure to wastewater in reuse schemes takes place. New technologies are developing that may enable routine and inexpensive monitoring of the more notable pathogens, such as, Norwalk virus, hepatitis A virus, *Cryptosporidium* and *Giardia*.

As these techniques are developed, further data from environmental sampling of high risk pathogens will need to be obtained for the purposes of providing a more accurate quantifiable health risk assessment of reuse schemes. With this information, risk managers may be in a better position to ascertain whether the guideline measures, STP and reuse management practices are adequate or need reviewing. This would help negate the potential occurrence of illness and unnecessary litigation.

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APPENDICES

Appendix 1	Detailed sampling programs for Rounds 1, 2 and 3.
Appendix 2	Preliminary study microbiological results
Appendix 3	Weather data from the Ti Tree Bend and Launceston Airport weather stations (Daily temperature, rainfall and bright sunshine hours for the irrigation season).
Appendix 4	t-test results between control and effluent-affected turfgrass and between effluent-affected irrigant and turfgrass samples for Round 3.
Appendix 5	Conductivity correlation concerning the influence of Na EDTA and Na thiosulfate in irrigant water samples.
Appendix 6	Irrigation and rainfall schedule in the test area.
Appendix 7	t -test for soil moisture comparison between rounds and between all control and effluent-affected samples.
Appendix 8	Calculation of estimated FC concentration on turfgrass based on depth of irrigant applied.
Appendix 9	Calculation of turfgrass FC/*E. coli* per 100 mL equivalent concentration on turfgrass.
Appendix 10	Basic epidemiological features of excreted pathogens by environmental category.
Appendix 11	National Water Quality Management Strategy (1996) *Draft Guidelines for the Use of Reclaimed Water* (NHMRC et al. 1996).

APPENDIX 1: ROUND 1 DETAILED SAMPLING PROGRAM AND MATERIALS REQUIRED (10-12/10)
(Day one - set up day, Day two - control sample collection, Day three - effluent-affected collection)

SAMPLE TYPE	METHOD OF COLLECTION	MATERIALS REQUIRED
STP EFFLUENT "STP"	1 - Collect 2 x 100mL samples of effluent into a sterilised jar. One to be collected at the beginning of filling of the holding pond (~ 10 am) and one to be collected at the end of filling the holding pond (4 pm). Measure effluent temp, cond, and pH and record on STP, HP & creek sampling data sheet. 2 - Mark jars "STP, 1 or 2, time, date".	- 2 x 100 mL presterilised bunzl jars with Na EDTA & Na Thiosulfate - 4°C storage container (may need more than one for about 220 samples) - Labels and marker pen (may need two sets) - Sterile gloves - STP, HP & creek sampling data sheet - thermometer, conductivity meter, pH meter
HOLDING POND "HP"	1 - Collect one sample of holding pond water just before irrigation on day two (5pm). Mark jar "HP BF, time, date". Measure water temp, conductivity and pH and record on STP, HP & creek sampling data sheet. 2 - Collect 3 x 100mL samples of holding pond water from the pump housing during the irrigation period - one at the beginning (~8pm), one at the middle (~11pm) and one at the end of the irrigation period (~3pm). 3 - Mark jars "HP, 2 or 3 or 4, time, date".	- 4 x 100mL presterilised bunzl jars with Na EDTA & Na Thiosulfate - 4°C storage container - Labels and marker pen - STP, HP & creek sampling data sheet - thermometer, conductivity meter, pH meter
CREEK "C"	1 - Collect 8 x 100mL samples of creek water at four premarked positions before (control) and after (effluent-affected) irrigation at 4 p.m. during day two and day three. Take water temp, cond and pH readings and record on STP, HP & creek sampling data sheet. Position 1: pond exit on 7th hole. Position 2: upstream of 5th hole at first bend. Position 3: midway between hole 3 & 5. Position 4: downstream from hole 3 ABOVE 'T' junction. 2 - Mark jars "CC or CT, 1 or 2 or 3 or 4, time, date".	- 8 x 100mL presterilised bunzl jars with Na EDTA & Na Thiosulfate - 4°C storage container - Labels and marker pen - STP, HP & creek sampling data sheet - thermometer, conductivity meter, pH meter
SOILS "S"	1 - Use same markers as for irrigant water samples. 2 - With syringe take a 5 composite core samples at a specific depth of 5 cm around 10 am on day two. Also take extra soil samples for moisture analysis. Measure soil temp, pH and conductivity. (Use 'Soil sampling data sheet' to record info). Refill holes with appropriate soil. 3 - Label jars, "SC, 1 to 12, time, date" . 4 - The same time next day repeat steps 2 & 3 labeling jars "ST, 1-12, time, date". (Multidepth sampling will be conducted on the 2nd & 3rd visits only).	- 12 x 5 cm min. length autoclavable syringes (at least) - 28 x sterilised bunzl jars - measuring tape - labels and marker pens - 4°C storage container - bucket of turf soil and trowel - Soil sampling data sheet - thermometer, conductivity meter, and pH meter.

SAMPLE TYPE	METHOD OF COLLECTION	MATERIALS REQUIRED
SURFACE IRRIGANT WATER "T"	1 - Position 12 markers in the test area at specified distances from the nearest sprinkler head on day one - see figure 1. (Need to locate sprinklers first). 2 - Place 12 open top containers on markers at the end of day one - leave overnight, (controls) and place a raingauge (in case precipitation occurs during the night). 3 - Collect water samples into the jars before days play (6am) on day two, take water temp, pH, conned, measurement, turbidity assessment on remaining water and lux readings and record on 'Irrigant water sampling data sheet'). 4 - Mark jars "TC, 1 to 12, time, date". 5 - Place 12 open top containers on markers and rain gauge at the end of day two (5pm) - leave overnight during irrigation period, (effluent-affected). 6 - Collect jars before days play (6am) on day three. Take physico-chemical readings. 7 - Mark jars "TT, 1-12, time, date"	- (24+3) x 100mL (at least) wide diameter presterilised containers (e.g. ice cream containers) 48 + extras tent pegs and 24 + extras bunzl jars with Na EDTA & Na thiosulfate - 4°C storage container - Labels and marker pen - 50m measuring tape - 12 x position markers (thick plastic sheet and pins) - Irrigant water sampling data sheet - Rain gauge. - thermometer, conductivity meter, pH meter and light meter.
GOLF BALLS "B" AND PLAYERS HANDS "P"	1 - On day two (control) select 3 sets of two willing volunteers (early morning - 8 am, late morning -11am, and early afternoon - 2 pm) entering the test area (hole no. 1) to presterilise their golf balls (or loan them new ones) and hands, by washing hands and golf balls in disinfectant, pre-rinse golf balls and swab hands by swabbing 50 cm^2 palm of both hands of each player. (Use 'Ball and Hands sampling data sheet' to record info). 2 - Collect and rinse their golf balls and swab their hands at the end of test area, hole no. 5, at about 1 1/4 hours after start of play. 3 - Mark samples "BMC or BOC or BAC, 1 to 4, time, date" for golf ball rinse bags. 4 - Mark sample jars "PMC or POC or PAC, 1 to 4, time, date" for player's hands swab samples. NB: No. 1 rinse bag for hand swab must match No.1 rinse bag for golf ball, i.e., the same player. 5 - Repeat the same procedure, steps 1-4, on day three, (effluent-affected) players hand samples as "PMT or POT or PAT, 1 to 4, time and date" and for the golf ball rinse bags label as "BMT or BOT or BAT, 1-4, time, date" 6 - Store samples in a cool container.	For golf balls - 12 golf balls (new) - 15 bunzl jars with 150mL 0.1% peptone water & 0.5% Tween 80 - bucket of disinfectant - sterilised towel or swab to dry ball For player's hands - 24 x swabs and Macartney tubes with 0.1% peptone water & 0.5% Tween 80 - jar of methanol and scissors - bucket of disinfectant - sterilised towel to dry hands - labels and marker pen - 4°C storage container - Ball and Hands sampling data sheet

SAMPLE TYPE	METHOD OF COLLECTION	MATERIALS REQUIRED
AEROSOLS "A"	1 - Use same markers as for irrigant water samples. 2 - Using the Anderson aerosol sampler and biostrips take 8 minute x 12 readings: mid-morning (8am), late morning (11am), and mid afternoon (2pm) on day two (control). 3 - Take wind speed, direction, air temperature, light intensity and humidity measurements for each sample (use 'Aerosol sampling data sheet'). 4 - Mark biostrips, " AMC or AOC or AAC, 1....9, time, date". 5 - Store strips in a 4°C container. 6 - repeat steps 2 to 5 for day three (effluent-affected sample) mark samples "AMT or AOT or AAT, 1....9, time, date". 7 - remove markers when finished.	- Anderson Sampler - Sampler stand that can be pegged into the ground - wind anemometer, wind flag compass - light meter, psychrometer, thermometer - recording sheet/pen - 24 biostrips - labels and markers - 4°C container - Aerosol sampling data sheet
PHYSICO-CHEMICAL & BIOCLIMATOLOGICAL PARAMETERS "PC"		
1 - Weather data	Rainfall, daily temperature range, humidity, wind data and light levels collect from Bureau of Meteorology for the nearest weather station.	Bureau of Met data
2 - Temperature 3 - Conductivity 4 - pH 5 - Visual comment on turbidity	Parameters 2 to 4 are to be done for soil water, irrigant water, holding pond, creek water, and STP effluent during each particular sample run at our discretion.	- Thermometer, conductivity meter, pH meter from Aquahealth
6 - Soil moisture	1- Take one composite soil sample for each sample to be collected. 2 - Weigh samples in lab, dry at 104°C for 24hrs then weigh again.	- Lab balance - Marker pen
7 - Soil infiltration rate	1 - to determine when best to take soil samples use two infiltometers on day one for various soils to determine the infiltration rates.	- Two infiltrometers from Ag. Sci. (Dr Richard Doyle) - Data sheet to plot graph.
8 - Soil and vegetation type	Ask Graham or Craig for types of grass and soils being used.	- Soil maps of Tasmania & DPIF (Rob Morton)
9 - Air moisture for aerosols	Take measurement before and after each aerosol sample collection.	- Psychrometer
10 - Air temperature	"	- "
11 - Light intensity	To be made for aerosols and irrigant water samples.	- light meter (David Sommerville)

APPENDIX 1: ROUND 2 DETAILED SAMPLING PROGRAM AND MATERIALS REQUIRED (6-8/11/95)
(Day one - set up day, Day two - control sample collection, Day three - effluent-affected collection)

SAMPLE TYPE	METHOD OF COLLECTION	MATERIALS REQUIRED
STP EFFLUENT "STP"	1 - Collect 2 x 100mL samples of effluent into a sterilised jar. One to be collected at the beginning of filling of the holding pond (~ 8 am) and one to be collected at the end of filling the holding pond (2 pm). Measure effluent temp, conductivity, and pH and record on STP, HP & creek sampling data sheet. 2 - Mark jars "STP, 1 or 2, time, date".	- 2 x 100 mL presterilised bunzl jars with Na EDTA & Na Thiosulfate - 4°C storage container (may need more than one for about 220 samples) - Labels and marker pen (may need two sets) - Sterile gloves - STP, HP & creek sampling data sheet - thermometer, conductivity meter, pH meter
HOLDING POND "HP"	1 - Collect 3 x 100mL samples of holding pond water from the pump housing during the irrigation period - one at the beginning (~8pm), one at the middle (~11pm) and one at the end of the irrigation period (~3pm) using sterile syringes. 2-Measure water temp, conductivity and pH and record on STP, HP & creek sampling data sheet. 3 - Mark jars "HP, 2 or 3 or 4, time, date".	- 3 x 100mL presterilised bunzl jars with Na EDTA & Na Thiosulfate - 4°C storage container - Labels and marker pen - STP, HP & creek sampling data sheet - thermometer, conductivity meter, pH meter
CREEK "C"	1 - Collect 8 x 100mL samples of creek water at four premarked positions before (control) and after (effluent-affected) irrigation at 4 p.m. during day two and day three. Take water temp, conductivity and pH readings and record on STP, HP & creek sampling data sheet. Position 1: pond exit on 7th hole. Position 2: upstream of 5th hole at first bend. Position 3: midway between hole 3 & 5. Position 4: middle bridge of hole 3. 2 - Mark jars "CC or CT, 1 or 2 or 3 or 4, time, date".	- 8 x 100mL presterilised bunzl jars with Na EDTA & Na Thiosulfate - 4°C storage container - Labels and marker pen - STP, HP & creek sampling data sheet - thermometer, conductivity meter, pH meter
SURFACE IRRIGANT WATER "T"	1 - Position 9 markers in the test area at specified distances from the nearest sprinkler head on day one - see figure 1. (Need to locate sprinklers first). 2 - Place 9 open top containers on markers at the end of day one - leave overnight, (controls) and place a raingauge (in case precipitation occurs during the night). 3 - Collect water samples into the jars before days play (6am) on day two, take lux readings and record on 'Irrigant water sampling data sheet'. 4 - Mark jars "TC, 1 to 12, time, date". 5 - Place 9 open top containers on markers and rain gauge at the end of day two (5pm) - leave overnight during irrigation period, (effluent-affected). 6 - Collect jars before days play (6am) on day three. Take physico-chemical readings. 7 - Mark jars "TT, 1-12, time, date". 8 - In lab take pH, conductivity and turbidity assessment on remaining water.	- 21 x 100mL (at least) wide diameter presterilised containers (e.g. ice cream containers) 48 + extras tent pegs and 24 + extras bunzl jars with Na EDTA & Na thiosulfate - 4°C storage container - Labels and marker pen - 50m measuring tape - 9 x position markers (thick plastic sheet and pins) - Irrigant water sampling data sheet - Rain gauge. - thermometer, conductivity meter, pH meter and light meter.

Prepared by S.D. Marrable 1996

SAMPLE TYPE	METHOD OF COLLECTION	MATERIALS REQUIRED
TURFGRASS SAMPLES "G"	1 - Using the same markers take a grass cutting, one just before irrigation (control) and one just after irrigation (effluent-affected), by using the soil corer supplied by the golf course at these locations, slice off the vegetation using a sterilised sharp knife and take core samples of the soil at the same time. 2 - Place grass cutting into a presterilised bunzl jar. 3 - Label bunzl jar "GC, 1-12, date" or "GT, 1-12, date". 4 - Place in cool container.	- 18 bunzl jars with Na EDTA & Na thiosulfate - Corer - Sharp knife - Gloves - Methanol - Paper towel - Labels and Pen - Turfgrass sampling data sheets
SOILS "S"	1 - Use same markers as for irrigant water samples. 2 - With syringe take a 5 composite core samples at a specific depth of 5 cm around 10 am on day two. Also take extra soil samples for moisture analysis. Measure soil temp, pH and conductivity. (Use 'Soil sampling data sheet' to record info). Refill holes with appropriate soil. 3 - Label jars, "SC, 1 to 12, time, date". 4 - The same time next day repeat steps 2 & 3 labeling jars "ST, 1-12, time, date".	- 12 x 5 cm minimum length autoclavable syringes (at least) - 18 x sterilised bunzl jars - measuring tape - labels and marker pens - 4°C storage container - bucket of turf soil and trowel - Soil sampling data sheet - thermometer, conductivity meter, and pH meter.
GOLF BALLS "B" AND PLAYERS HANDS "P"	1 - On day two (control) select 3 sets of 4 willing volunteers (early morning - 9 am, late morning -11am, and early afternoon - 2 pm) entering the test area (hole no. 1) to give them a presterilise golf ball each rinsed in methanol and sterilising their hands by washing them in disinfectant, swab hands by swabbing 300 cm^2 palm of both hands of each player. (Use 'Ball and Hands sampling data sheet' to record info). NB: Encourage players not to wash their balls and to use our sterilised towels if they need to wipe them. 2 - Collect and rinse their golf balls and swab their hands at the end of test area, hole no. 5, at about 1 1/4 hours after start of play. 3 - Mark samples "BMC or BOC or BAC, 1 to 4, time, date" for golf ball bunzl jars. 4 - Mark bunzl jars "PMCB/A or POCB/A or PACB/A, 1 to 4, time, date" for player's hands swab samples. NB: No. 1 rinse bag for hand swab must match No.1 rinse bag for golf ball, i.e., the same player. 5 - Repeat the same procedure, steps 1-4, on day three, (effluent-affected) for the golf ball samples labeling as "BMT or BOT or BAT, 1-4, time, date" and player's hand samples as "PMTB/A or POTB/A or PATB/A, 1 to 4, time and date". 6 - Store samples in a cool container.	For golf balls - 24 golf balls (new) - 24 bunzl jars with 150mL 0.1% peptone water & 0.5% Tween 80 - bucket of disinfectant - sterilised towel or swab to dry ball For player's hands - 48 x swabs and Macartney tubes with 0.1% peptone water & 0.5% Tween 80 - jar of methanol and scissors - bucket of disinfectant - sterilised towel to dry hands - labels and marker pen - 4°C storage container - Ball and Hands sampling data sheet

SAMPLE TYPE	METHOD OF COLLECTION	MATERIALS REQUIRED
AEROSOLS "A"	1 - Use same markers as for irrigant water samples. 2 - Using the Anderson aerosol sampler and biostrips take 4 minute x 9 readings: mid-morning (8am), late morning (11am), and mid afternoon (2pm) on day two (control). 3 - Take wind speed, direction, air temperature, light intensity and humidity measurements for each sample (use 'Aerosol sampling data sheet'). 4 - Mark biostrips, " AMC or AOC or AAC, 1....9, time, date". 5 - Store strips in a 4°C container. 6 - repeat steps 2 to 5 for day three (effluent-affected sample) mark samples "AMT or AOT or AAT, 1....9, time, date" 7 - remove markers when finished.	- Anderson Sampler - Sampler stand that can be pegged into the ground - wind anemometer, wind flag compass - light meter, psychrometer, thermometer - recording sheet/pen - 24 biostrips - labels and markers - 4°C container - Aerosol sampling data sheet
PHYSICO-CHEMICAL & BIOCLIMATOLOGICAL PARAMETERS "PC"		
1 - Weather data	Rainfall, daily temperature range, humidity, wind data and light levels collect from Bureau of Meteorology for the nearest weather station.	Bureau of Met data, personal rain gauge and rain gauge data off the golf course staff.
2 - Temperature 3 - Conductivity 4 - pH 5 - Visual comment on turbidity	Parameters 2 to 4 are to be done for soil water, irrigant water, holding pond, creek water, and STP effluent during each particular sample run at our discretion. Or use Spectrometer in Denis' lab.	- Thermometer, conductivity meter, pH meter from Aquahealth
6 - Soil moisture	1- Take one composite soil sample for each sample to be collected. 2 - Weigh samples in lab, dry at 104°C for 24hrs then weigh again.	- Lab balance - Marker pen
9 - Air moisture for aerosols	Take for each sample.	- Psychrometer
10 - Air temperature	To be made for aerosols and irrigant water samples.	- "
11 - Light intensity	"	- light meter (David Sommerville)

APPENDIX 1: ROUND 3 DETAILED SAMPLING PROGRAM AND MATERIALS REQUIRED (25-27/3/96)
(Day one - set up day, Day two - control sample collection, Day three - effluent-affected collection)

SAMPLE TYPE	METHOD OF COLLECTION	MATERIALS REQUIRED
STP EFFLUENT "STP"	1 - Collect 2 x 100mL samples of effluent into a sterilised jar. One to be collected at the beginning of filling of the holding pond (~ 8 am) and one to be collected at the end of filling the holding pond (2 pm). Measure effluent temp, conductivity, and pH and record on STP, HP & creek sampling data sheet 2 - Mark jars "STP, 1 or 2, time, date".	- 2 x 100 mL presterilised bunzl jars with Na EDTA & Na Thiosulfate - 4°C storage container (may need more than one for about 220 samples) - Labels and marker pen (may need two sets) - Sterile gloves - STP, HP & creek sampling data sheet - thermometer, conductivity meter, pH meter
HOLDING POND "HP"	1 - Collect 3 x 100mL samples of holding pond water from the pump housing during the irrigation period - one at the beginning (~8pm), one at the middle (~11pm) and one at the end of the irrigation period (~3pm) using sterile syringes. 2-Measure water temp, conductivity and pH and record on STP, HP & creek sampling data sheet. 3 - Mark jars "HP, 2 or 3 or 4, time, date".	- 3 x 100mL presterilised bunzl jars with Na EDTA & Na Thiosulfate - 4°C storage container - Labels and marker pen - STP, HP & creek sampling data sheet - thermometer, conductivity meter, pH meter
CREEK "C"	1 - Collect 8 x 100mL samples of creek water at four premarked positions before (control) and after (effluent-affected) irrigation at 4 p.m. during day two and day three. Take water temp, conductivity and pH readings and record on STP, HP & creek sampling data sheet. Position 1: pond exit on 7th hole. Position 2: upstream of 5th hole at first bend. Position 3: midway between hole 3 & 5. Position 4: middle bridge of hole 3. 2 - Mark jars "CC or CT, 1 or 2 or 3 or 4, time, date".	- 8 x 100mL presterilised bunzl jars with Na EDTA & Na Thiosulfate - 4°C storage container - Labels and marker pen - STP, HP & creek sampling data sheet - thermometer, conductivity meter, pH meter
SURFACE IRRIGANT WATER "T"	1 - Position 9 markers in the test area at specified distances from the nearest sprinkler head on day one - see figure 1. (Need to locate sprinklers first). 2 - Place 9 open top containers on markers at the end of day one - leave overnight, (controls) and place a rainmeter (in case precipitation occurs during the night). 3 - Collect water samples into the jars before days play (6am) on day two, take lux readings and record on 'Irrigant water sampling data sheet'. 4 - Mark jars "TC, 1 to 12, time, date". 5 - Place 9 open top containers on markers and rain gauge at the end of day two (5pm) - leave overnight during irrigation period, (effluent-affected). 6 - Collect jars before days play (6am) on day three. Take physico-chemical readings. 7 - Mark jars "TT, 1-12, time, date". 8 - In lab take pH, conductivity and turbidity assessment on remaining water.	- 21 x 100mL (at least) wide diameter presterilised containers (e.g. ice cream containers) 48 + extras tent pegs and 24 + extras bunzl jars with Na EDTA & Na thiosulfate - 4°C storage container - Labels and marker pen - 50m measuring tape - 9 x position markers (thick plastic sheet and pins) - Irrigant water sampling data sheet - Rain gauge. - thermometer, conductivity meter, pH meter and light meter.

SAMPLE TYPE	METHOD OF COLLECTION	MATERIALS REQUIRED
TURFGRASS SAMPLES "G"	1 - Using the same markers take a grass cutting, one just before irrigation (control) and one just after irrigation (effluent-affected), by using the soil corer supplied by the golf course at these locations, slice off the vegetation using a sterilised sharp knife and take core samples of the soil at the same time. 2 - Place grass cutting into a stomacher bag, add 2x90mL peptone water, seal and shake contents for 30 seconds. 3 - carefully take out the turfgrass cutting and place back in the ground. Carefully decant supernatant into a presterilised bunzl jar. 3 - Label bunzl jar "GC, 1-12, date" or "GT, 1-12, date". 4 - Place in cool container.	- 18 stomacher bags - 18 bunzl jars with Na EDTA & Na thiosulfate - 39 x 90mL peptone waters. - Corer - Sharp knife - Gloves - Methanol - Paper towel - Labels and Pen - Turfgrass sampling data sheets
SOILS "S"	1 - Use same markers as for irrigant water samples. 2 - With syringe take a 5 composite core samples at a specific depth of 5 cm around 10 a.m. on day two. Also take extra soil samples for moisture analysis. Measure soil temp, pH and conductivity. (Use 'Soil sampling data sheet' to record info). Refill holes with appropriate soil. 3 - Label jars, "SC, 1 to 12, time, date". 4 - The same time next day repeat steps 2 & 3 labeling jars "ST, 1-12, time, date".	- 12 x 5 cm minimum length autoclavable syringes (at least) - 18 x sterilised bunzl jars - measuring tape - labels and marker pens - 4°C storage container - bucket of turf soil and trowel - Soil sampling data sheet - thermometer, conductivity meter, and pH meter.
GOLF BALLS "B" AND PLAYERS HANDS "P"	1 - On day two (control) select 3 sets of 4 willing volunteers (early morning - 9 am, late morning -11am, and early afternoon - 2 pm) entering the test area (hole no. 1) to give them a presterilise golf ball each rinsed in methanol and sterilising their hands by washing them in disinfectant, swab hands by swabbing 300 cm^2 palm of both hands of each player. (Use 'Ball and Hands sampling data sheet' to record info). NB: Encourage players not to wash their balls and to use our sterilised towels if they need to wipe them. 2 - Collect and rinse their golf balls and swab their hands at the end of test area, hole no. 5, at about 1 1/4 hours after start of play. 3 - Mark samples "BMC or BOC or BAC, 1 to 4, time, date" for golf ball bunzl jars. 4 - Mark bunzl jars "PMC before/after or POC before/after or PAC before/after, 1 to 4, time, date" for player's hands swab samples. NB: No. 1 rinse bag for hand swab must match No.1 rinse bag for golf ball, i.e., the same player. 5 - Repeat the same procedure, steps 1-4, on day three, (effluent-affected) for the golf ball samples labeling as "BMT or BOT or BAT, 1-4, time, date" and player's hand samples as "PMT before/after or POT before/after or PAT before/after, 1 to 4, time and date". 6 - Store samples in a cool container.	For golf balls - 24 golf balls (new) - 24 bunzl jars with 150mL 0.1% peptone water & 0.5% Tween 80 - bucket of disinfectant - sterilised towel or swab to dry ball For player's hands - 48 x swabs and Macartney tubes with 0.1% peptone water & 0.5% Tween 80 - jar of methanol and scissors - bucket of disinfectant - sterilised towel to dry hands - labels and marker pen - 4°C storage container - Ball and Hands sampling data sheet

SAMPLE TYPE	METHOD OF COLLECTION	MATERIALS REQUIRED
AEROSOLS "A"	1 - Use same markers as for irrigant water samples. 2 - Using the Anderson aerosol sampler and biostrips take 4 minute x 9 readings: mid-morning (8am), late morning (11am), and mid afternoon (2pm) on day two (control). 3 - Take wind speed, direction, air temperature, light intensity and humidity measurements for each sample (use 'Aerosol sampling data sheet'). 4 - Mark biostrips, " AMC or AOC or AAC, 1....9, time, date". 5 - Store strips in a 4°C container. 6 - repeat steps 2 to 5 for day three (effluent-affected sample) mark samples "AMT or AOT or AAT, 1....9, time, date". 7 - remove markers when finished.	- Anderson Sampler - Sampler stand that can be pegged into the ground - wind anemometer, wind flag compass - light meter, psychrometer, thermometer - recording sheet/pen - 24 biostrips - labels and markers - 4°C container - Aerosol sampling data sheet
PHYSICO-CHEMICAL & BIOCLIMATOLOGICAL PARAMETERS "PC"		
1 - Weather data	Rainfall, daily temperature range, humidity, wind data and light levels collect from Bureau of Meteorology for the nearest weather station.	Bureau of Met data, personal rain gauge and rain gauge data off the golf course staff.
2 - Temperature 3 - Conductivity 4 - pH 5 - Visual comment on turbidity	Parameters 2 to 4 are to be done for soil water, irrigant water, holding pond, creek water, and STP effluent during each particular sample run at our discretion. Or use Spectrometer in Denis' lab.	- Thermometer, conductivity meter, pH meter from Aquahealth
6 - Soil moisture	1- Take one composite soil sample for each sample to be collected. 2 - Weigh samples in lab, dry at 104°C for 24hrs then weigh again.	- Lab balance - Marker pen
9 - Air moisture for aerosols	Take for each sample.	- Psychrometer
10 - Air temperature	To be made for aerosols and irrigant water samples.	- "
11 - Light intensity	"	- light meter (David Sommerville)

AQUAHEALTH
NATA Registered Laboratory No. 3314
(Biological Testing)

MICROBIOLOGICAL RESULTS FORM Water (1995)

Submitted by: C Garland/S Marrable
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Phone: (002)207455
Fax: (002)202989
Organisation: Dept of Geography and Environmental Studies
University of Tasmania

Report No. W76/95
Page: 1 of 1

SIGNED: C Garland

Date report issued: 19/6/95

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Sample No.	Lab No.	Sample Type	Sample Site	Sample Use	Time and Date Colected	Date Sub-mitted	Date of Tests	Tests* Required	Results FC /100mL	Results *E.coli* /100mL
1	W6/33	Creek Water	Top of Creek	Ambient	3.20pm,14/6/95	14/6/95	14/6/95	FC/*E.coli*	<1 000	<1 000
5	W6/36	"	Middle of Creek	"	3.35pm, "	"	"	"	300	<100
2	W6/34	"	Bottom of Creek	"	3.30pm, "	"	"	"	1 700	1 700
3	W6/35	Pond Water	STP Effluent Pond	"	" "	"	"	"	1 500	1 300
8	W6/38	Surface Water	Top Fairway	"	3.55pm, "	"	"	"	400	200
6	W6/37	"	12th Fairway-Above Pond	"	3.40pm, "	"	"	"	300	300

* Tests were performed on samples as received TC=Total Coliforms, FC=Faecal Coliforms

National Association of Testing Authorities, Australia

Appendix 2
Pilot Study Microbiological Results

AQUAHEALTH
NATA Registered Laboratory No. 3314
(Biological Testing)

University of Tasmania
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MICROBIOLOGICAL RESULTS FORM Swab (1995)

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University of Tasmania

Report No. S11/95
Page: 1 of 1

SIGNED: C Garland

Date report issued: 20/6/95

Sample No.	Lab No.	Sample Type	Sample Site	Time and Date Colected	Date Sub-mitted	Date of Tests	Tests* Required	Results SPC /50cm^2
4	S6/31	Swab	Hands - G.Simmons	3.35pm,14/6/95	14/6/95	14/6/95	SPC	1 760
7	S6/32	"	Hands - Player	3.45pm, "	"	"	"	100 000 (est)

* Tests were performed on samples as received
SPC = Satndard Plate Count

Appendix 2
Pilot Study Microbiological Results

MICROBIOLOGICAL RESULTS FORM Air (1995)

Submitted by : C Garland/S Marrables **Organisation:** Dept. of Geography & Env. Studies
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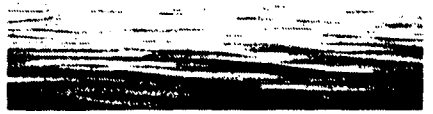
Report No. A11/95
Page 1 **of** 1
Signed: C Garland
Date report issued: 20/6/95

AQUAHEALTH
NATA Registered Laboratory No. 3314
(Biological Testing)



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Sample No.	Lab No.	Sample Type	Sample Site	Time & Date Collected	Date Sub-mitted	Date of Tests	Tests* Required	Results SPC /m^3	Results Y&M /m^3
3	A6/3	Biotest Air Strip (80L)	Top of creek	3.55pm, 14/6/95	15/6/95	15/6/95	SPC	88	
2	A6/2	" (80L)	Near STP effluent pond	3.45pm, "	"	"	"	63	
1	A6/1	" (80L)	North of main maintenance shed	3.30pm, "	"	"	"	63	

*Tests were performed on samples as received

SPC=Standard Plate Count, Y&M =Yeasts & Moulds

Appendix 2
Pilot Study Microbiological Results

APPENDIX 2

West Tamar Council and Pilot Study Microbiological Results

PILOT STUDY AND COUNCIL BACTERIAL DATA					
West Tamar Council Bacteriological Examination of Wastewater					
Date	Time sampled	Time received for analysis	WWTP effluent *E.coli*/ 100 mL	Holding Pond *E.coli*/ 100 mL	
9/11/94	10:30 AM	11:00 AM	20		
30/11/94	10:20 AM	10:55 AM		90	
30/11/94	10:25 AM	10:55 AM	<10		
7/12/94	12:55 PM	1:50 PM	<100		
7/12/94	1:00 PM	1:50 PM		500	
14/12/94	10:30 AM	11:00 AM	<100		
14/12/94	10:35 AM	11:00 AM		100	
11/01/95	9:30 AM	10:15 AM	100		
15/02/95		2:20 PM	600		
15/03/95		10:25 AM	<100		
29/03/95	10:30 AM	11:15 AM	<10		
5/04/95	10:30 AM	11:15 AM	20		
16/05/95		11:10 AM	<100		
12/07/95		12:05 PM	<20		
Pilot sample					
19/06/95	3:30 PM			1300	

Up until 1/1/95 the STP effluent discharge pipe was partially submerged making sampling difficult. Some mixing with the holding pond water did take place.

Daily Rainfall to 9am (mm)

Period over which rainfall has accumulated (days)

LAUNCESTON (TI TREE BEND)

Station Number 091237
41°25'15"S 147°07'22"E
Elevation 5 metres

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Avg	Max	Min	Sum	Nbr
Oct 1995	0.8	0.0	0.6	0.0	0.2	2.0	7.4	2.8	0.0	0.0	3.6	0.0	20.6	0.4	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.0	6.6	0.0	1.8	20.6	0.0	55.8	31
	1	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1.0*	*1*	*1*	*31*	*31*
Nov 1995	0.0	2.4	0.4	0.0	1.0	0.0	1.4	1.6	0.0	1.0	1.4	1.6	0.0	0.0	5.6	0.0	0.0	9.0	0.6	0.0	0.0	8.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2		1.1	9.0	0.0	34.2	30
	1	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*		*1.0*	*1*	*1*	*30*	*30*
Dec 1995	1.8	0.0	0.0	3.4	18.6	0.0	0.0	0.0	0.0	3.6	0.8	0.0	0.0	0.0	0.0	0.0	0.0	21.8	8.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	21.8	0.0	58.6	31
	1	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1.0*	*1*	*1*	*31*	*31*
Jan 1996	13.8	16.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.2	0.2	0.0	15.0	45.4	16.4	16.6	3.0	0.4	0.0	0.0	4.5	45.4	0.0	139.4	31
	1	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1.0*	*1*	*1*	*31*	*31*
Feb 1996	9.0	0.0	0.0	0.0	0.0	5.8	0.0	0.0	16.0	5.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.4	0.6			1.7	16.0	0.0	50.6	29
	1	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*			*1.0*	*1*	*1*	*29*	*29*
Mar 1996	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	22.0	0.0	0.0	3.0	0.2	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	10.0	2.0	1.4	22.0	0.0	43.2	31
																1	*1*			*1*	*1*						*1*			*1*	*1*	*1.0*	*1*	*1*	*7*	*7*

Summary of Daily Rainfall to 9am (mm) for Oct 1995 to Mar 1996	2.1	45.4	0.0	381.8	183
Summary of Period over which rainfall has accumulated (days) for Oct 1995 to Mar 1996	*1.0*	*1*	*1*	*159*	*159*

Maximum Temperature from 9am (°C)

Minimum Temperature to 9am (°C)

LAUNCESTON (TI TREE BEND)

Station Number 091237
41°25'15"S 147°07'22"E
Elevation 5 metres

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Avg	Max	Min	Sum	Nbr
Oct 1995	21.0	19.0	16.0		16.0	16.0	14.0	17.0	16.0	18.0	17.0	15.0	18.0	18.0	19.0	16.0	19.0	18.0	21.0	15.0	16.0	19.0	21.0	18.0	18.0	18.0	19.0	18.0	18.0	17.0	17.0	17.6	21.0	14.0	528.0	30
	10.0	*11.0*	*9.0*	*1.0*		*8.0*	*9.0*	*4.0*	*1.0*	*6.0*	*7.0*	*2.0*	*8.0*	*5.0*	*2.0*	*3.0*	*7.0*	*4.0*	*9.0*	*5.0*	*3.0*	*3.0*	*7.0*	*10.0*	*7.0*	*8.0*	*5.0*	*10.0*	*5.0*	*5.0*	*2.0*	*5.9*	*11.0*	*1.0*	*176.0*	*30*
Nov 1995	16.0	20.0	20.0	19.0	15.0	14.0	19.0	19.0	20.0	17.0	19.0	20.0	21.0	20.0	23.0	22.0	23.0	24.0	17.0	18.0	19.0	17.0	21.0	19.0	19.0	17.0	21.0	23.0	19.0	19.0		19.3	24.0	14.0	580.0	30
	6.0	*11.0*	*5.0*	*7.0*	*9.0*	*9.0*	*9.0*	*10.0*	*7.0*	*10.0*	*7.0*	*5.0*	*5.0*	*9.0*	*9.0*	*6.0*	*8.0*	*14.0*	*7.0*	*5.0*	*10.0*	*12.0*	*8.0*	*10.0*	*8.0*	*9.0*	*9.0*	*12.0*	*6.0*	*8.0*		*8.3*	*14.0*	*5.0*	*250.0*	*30*
Dec 1995	22.0	19.0	20.0	19.0	21.0	24.0	21.0	23.0	25.0	17.0	18.0	17.0	20.0	23.0	22.0	25.0	19.0	21.0	19.0	21.0	18.0	20.0	19.0	22.0	20.0	24.0	20.0	25.0	28.0	23.0	21.0	21.2	28.0	17.0	656.0	31
	9.0	*7.0*	*13.0*	*11.0*	*8.0*	*6.0*	*7.0*	*11.0*	*8.0*	*11.0*	*4.0*	*2.0*	*9.0*	*6.0*	*9.0*	*11.0*	*12.0*	*13.0*	*13.0*	*14.0*	*9.0*	*8.0*	*8.0*	*8.0*	*8.0*	*10.0*	*10.0*	*9.0*	*9.0*	*9.0*	*17.0*	*9.3*	*17.0*	*2.0*	*289.0*	*31*
Jan 1996	18.0	22.0	22.0	23.0	22.0	25.0	26.0	25.0	29.0	28.0	27.0	24.0	24.0	27.0	27.0	25.0	25.0	27.0	27.0	27.0	19.0	23.0	22.0	21.0	17.0	21.0	19.0	21.0	24.0	23.0	23.0	23.6	29.0	17.0	733.0	31
	17.0	*13.0*	*11.0*	*7.0*	*9.0*	*8.0*	*15.0*	*13.0*	*13.0*	*13.0*	*11.0*	*16.0*	*16.0*	*11.0*	*15.0*	*12.0*	*10.0*	*14.0*	*12.0*	*15.0*	*9.0*	*8.0*	*8.0*	*14.0*	*12.0*	*10.0*	*13.0*	*9.0*	*12.0*	*12.0*	*15.0*	*12.0*	*17.0*	*7.0*	*373.0*	*31*
Feb 1996	22.0	20.0	21.0	18.0	24.0	20.0		18.0	19.0	21.0	22.0	19.0	20.0	25.0	24.0	22.0	24.0	24.0	22.0	21.0	24.0	27.0	27.0	26.0	25.0	26.0	18.0	19.0	20.0			22.1	27.0	18.0	618.0	28
	13.0	*10.0*	*7.0*	*10.0*	*13.0*	*12.0*	*13.0*	*13.0*	*12.0*	*14.0*	*8.0*	*7.0*	*5.0*	*9.0*	*10.0*	*11.0*	*13.0*	*14.0*	*16.0*	*13.0*	*9.0*	*12.0*	*12.0*	*11.0*	*13.0*	*14.0*	*14.0*	*12.0*	*7.0*			*11.3*	*16.0*	*5.0*	*327.0*	*29*
Mar 1996	23.0	19.0	25.0	24.0	24.0	26.0	21.0	23.0	24.0	21.0	23.0	26.0	24.0	22.0	21.0	21.0	16.0	21.0	17.0	16.0	21.0	23.0	19.0	23.0	24.0	25.0	23.0	23.0	23.0	21.0	19.0	22.0	26.0	16.0	681.0	31
	11.0	*5.0*	*10.0*	*9.0*	*14.0*	*16.0*	*9.0*	*8.0*	*9.0*	*12.0*	*13.0*	*12.0*	*12.0*	*7.0*	*6.0*	*9.0*	*10.0*	*7.0*	*5.0*	*5.0*	*6.0*	*5.0*	*7.0*	*11.0*	*8.0*	*10.0*	*11.0*	*12.0*	*15.0*	*16.0*	*12.0*	*9.7*	*16.0*	*5.0*	*302.0*	*31*

Summary of Maximum Temperature from 9am (°C) for Oct 1995 to Mar 1996	21.0	29.0	14.0	3796.0	181
Summary of Minimum Temperature to 9am (°C) for Oct 1995 to Mar 1996	*9.4*	*17.0*	*1.0*	*1717.0*	*182*

Bright Sunshine Duration (hours)

LAUNCESTON AIRPORT WSO

Station Number 091104
41°32'26"S 147°12'06"E
Elevation 170 metres

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Avg	Max	Min	Sum	Nbr
Oct 1995	6.9	9.0	5.0	11.3	3.5	10.6	7.2	11.6	11.7	5.5	11.7	5.4	4.3	12.0	10.2	10.3	10.4	9.6	4.3	11.6	11.2	11.6	8.6	9.7	12.6	8.1	9.6	5.1	5.8	10.9	12.3	9.0	12.6	3.5	277.6	31
Nov 1995	5.3	3.0	11.3	4.7	4.5	0.8	10.4	3.0	5.5	7.0	10.8	13.0	8.0	1.0	8.9	13.2	8.9	10.6	7.4	8.1	2.6	7.2	11.4	10.7	12.6	3.0	8.3	12.8	9.3	7.6		7.7	13.2	0.8	230.9	30
Dec 1995	13.2	10.0	6.3	3.6	12.9	13.0	9.2	12.0	4.1	9.9	11.2	11.6	10.8	13.3	8.8	11.2	0.1	2.9	2.2	4.6	10.5	8.9	13.0	10.7	9.7	11.2	5.0	13.4	13.3	2.0	0.0	8.7	13.4	0.0	268.6	31
Jan 1996	0.0	2.8	13.4	13.1	9.1	13.2	13.4	9.3	11.0	13.5	13.0	3.9	7.9	12.9	11.4	13.4	13.3	13.3	11.4	5.2	8.7	13.0	9.1	0.0	5.8	6.0	4.6	9.1	8.9	8.7	8.7	9.3	13.5	0.0	287.1	31
Feb 1996	5.6	9.2	7.4	1.4	8.9	3.5	2.1	0.0	3.7	10.3	8.1	12.9	12.9	8.4	11.2	12.3	11.1	7.7	0.0	6.7	11.7	12.2	11.5	12.4	12.0	12.3	1.9	1.0	9.3			7.9	12.9	0.0	227.7	29
Summary of Bright Sunshine Duration (hours) for Oct 1995 to Feb 1996																																8.5	13.5	0.0	1291.9	152

March 1996	25	26	27	28	Avg	Max	Min	Sum	Nbr
hours	9.5	4.0	8.7	8.1	7.2	11.5	4.0	222.6	31

t-Test Results Between Control and Effluent-Affected Turfgrass and Between Effluent-Affected Irrigant and Turfgrass Samples for Round 3

ROUND 3 't' TEST

Control (before irrigation)
Date: 26/3/96

	Irrigant T		Turgrass G	
Site	Faecal coliforms /100 mL	*E. coli* /100 mL	Faecal coliforms /100 mL eq	*E. coli* /100 mL eq
1	nt	nt	480	480
2	nt	nt	17	17
3	nt	nt	56	56
5	nt	nt	920	920
6	nt	nt	360	360
7	nt	nt	80	80
9	nt	nt	50	50
10	nt	nt	7	7
12	nt	nt	18	18

Effluent Affected (after irrigation)
Date: 27/3/96 Previous 24 hrs rainfall: 2.0 mm

1	1 300	1 300	11 000	11 000
2	900	900	66	66
3	7 300	7 300	70	70
5	900	900	320	320
6	600	600	110	110
7	1 200	1 200	130	130
9	500	500	1 000	1 000
10	1 100	1 100	70	70
12	600	600	13 000	13 000

Comparing effluent affected irrigant and turfgrass samples

Irrigant T	Turgrass G	Irrigant T log10	Turgrass G log10
1 300	11 000	3.114	4.041
900	66	2.954	1.820
7 300	70	3.863	1.845
900	320	2.954	2.505
600	110	2.778	2.041
1 200	130	3.079	2.114
500	1 000	2.699	3.000
1 100	70	3.041	1.845
600	13 000	2.778	4.114

t-Test: Paired Two Sample for Means on log values

	Irrigant T	Turgrass G
Mean	3.029	2.592
Variance	0.119	0.854
Observations	9	9
Pearson Correlation	-0.332	
Hypothesized Mean Difference	0	
df	8	
t Stat	1.205	
P(T<=t) one-tail	**0.131**	
t Critical one-tail	1.860	
P(T<=t) two-tail	0.263	
t Critical two-tail	2.306	

Comparing turfgrass control and effluent affected

Control	Effluent Affected	Control log10	Effluent Affected log10
480	11 000	2.681	4.041
17	66	1.230	1.820
56	70	1.748	1.845
920	320	2.964	2.505
360	110	2.556	2.041
80	130	1.903	2.114
50	1 000	1.699	3.000
7	70	0.845	1.845
18	13 000	1.255	4.114

t-Test: Paired Two Sample for Means on log values

	Control	Effluent Affected
Mean	1.876	2.592
Variance	0.526	0.854
Observations	9	9
Pearson Correlation	0.192	
Hypothesized Mean Difference	0	
df	8	
t Stat	-2.027	
P(T<=t) one-tail	**0.039**	
t Critical one-tail	1.860	
P(T<=t) two-tail	0.077	
t Critical two-tail	2.306	

APPENDIX 5

Conductivity Correlation Concerning the Influence of Na EDTA and Na Thiosulfate in Irrigant Water Samples

Conductivity Irrigant regression analysis

Instrument used: WTW

Sample	K (with) µS/cm	K(without) µS/cm		Regression analysis on K	
Round 1				without	with
STP1	786	888		888	786
STP2	867	911		911	867
				2 690	2 530
HPBF	2 530	2 690		2 810	2 370
HPAF	2 370	2 810		2 490	2 590
				3 590	4 240
CC1	2 590	2 490		3 890	4 500
CC2	4 240	3 590		1 250	1 270
CC3	4 500	3 890		2 560	2 550
CC4	1 270	1 250		4 250	4 350
CT1	2 550	2 560		4 630	4 680
CT2	4 350	4 250		2 020	1 990
CT3	4 680	4 630		1 314	1 687
CT4	1 990	2 020		1 380	1 950
				1 339	2 070
Round 2				953	1 383
				976	1 357
HP 1		1 314		1 001	1 144
HP 2		1 380		69	449
HP 3		1 339			
				SUMMARY OUTPUT	
TT1	1 687	1 314		*Regression Statistics*	
TT2	1 950	1 380		Multiple R	0.97096
TT3	2 070	1 339		R Square	0.94276
				Adjusted R	0.93939
Round 3				Standard Er	323.986
				Observatio	19
HP 1		953			
HP 2		976		ANOVA	
HP 3		1 001			*df*
				Regression	1
TT5	1 383	953		Residual	17
TT6	1 357	976		Total	18
TT7	1 144	1 001			
					Coefficient
Calibration test with deionised water				Intercept	246.927
			Temp °C	X Variable	0.97591
Deionised water	449	69	17.6		
Deionised water plus 1.5mL of 2.5M NaOH	21 700	25 800	17.1		

	SS	*MS*	*F*	*Significance F*
Regression	2.9E+07	2.9E+07	280.001	5.4E-12
Residual	1784436	104967		
Total	3.1E+07			

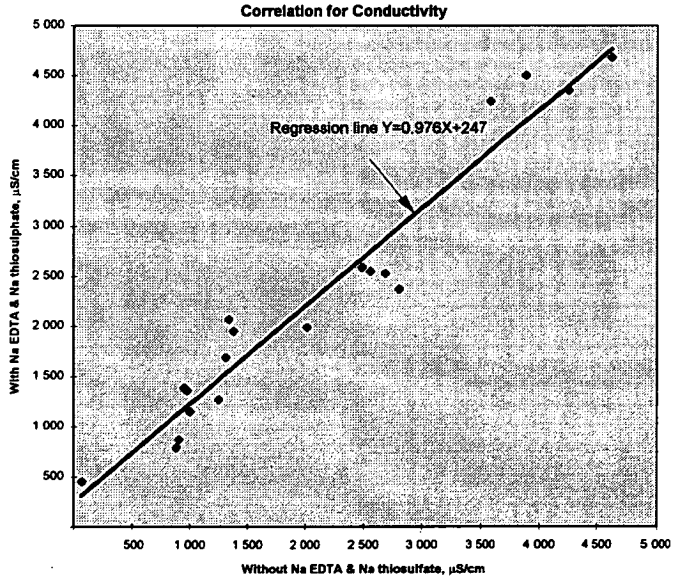
Standard	*t Stat*	*P-value*	*ower 95*	*pper 95*
140.94	1.752	0.09779	-50.4303	544.284
0.05832	16.7332	5.4E-12	0.85286	1.09896

Shaded data do not comprise of direct correlations of the same sample nevertheless they were paired since the holding pond effluent is viewed as essentially the same for the irrigant water in terms of conductivity.

The regression line has the form Y = aX+b. In this case Y is conductivity with Na EDTA and Na thiosulfate and X is the corresponding conductivity without them, a = 0.976 and b = 247 to 3 significant figures. Therefore the regression line takes the form:

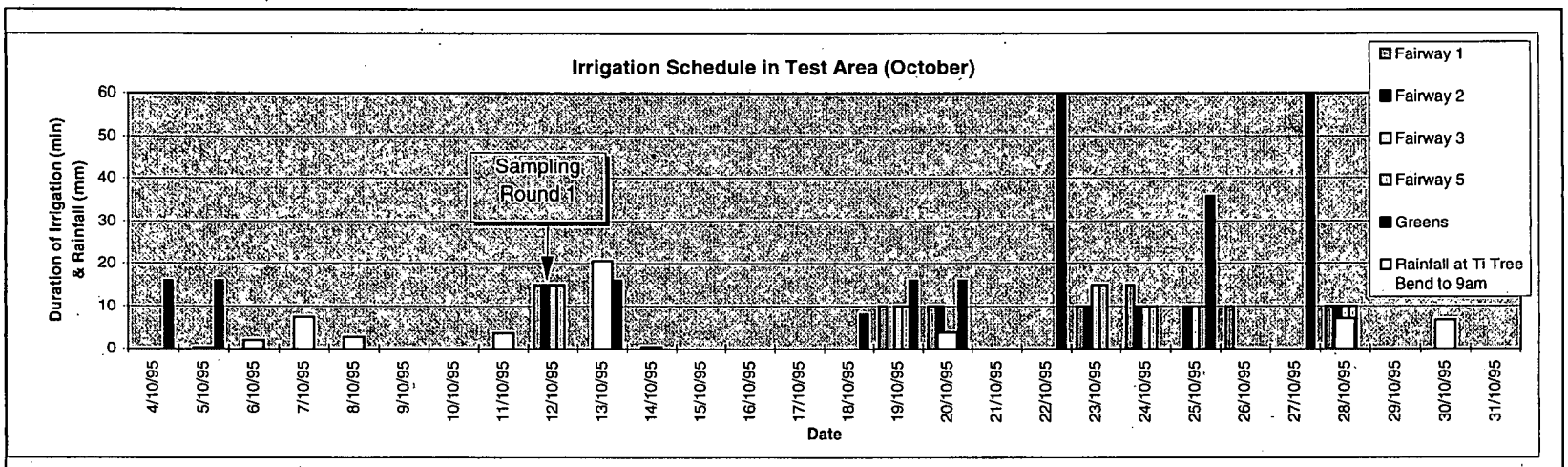
Y = 0.976X + 247 or X = (Y-247)/0.976 for known values of Y.

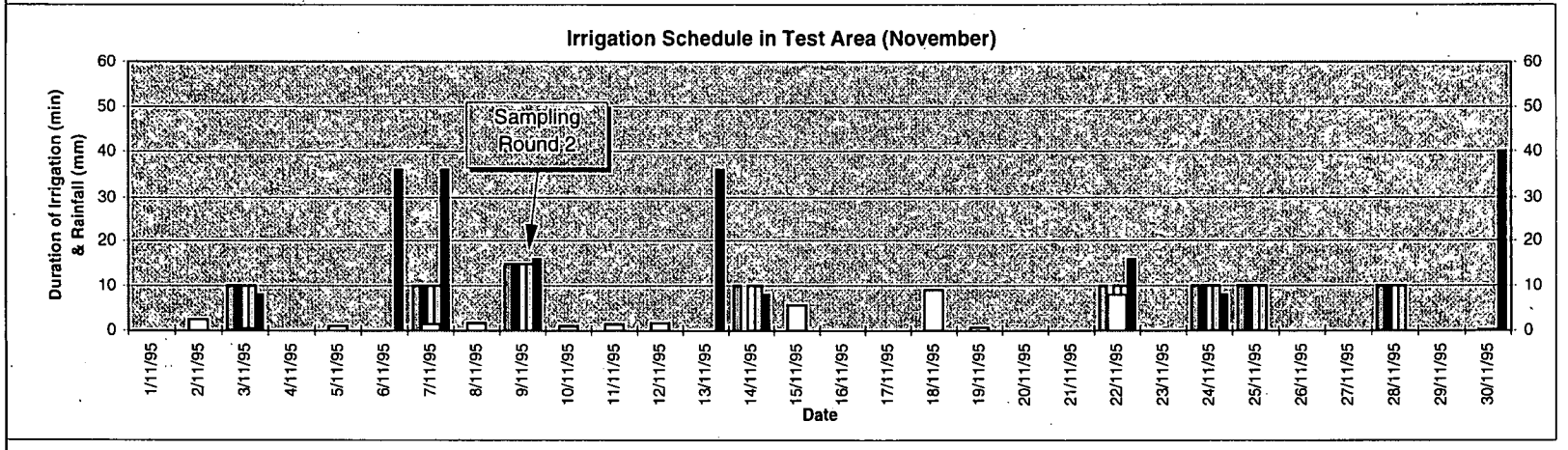
Sample	K (with) known	K (without) regression result
Round 1		
TC1	396	153
TC2	381	137
TC3	370	126
TC4	470	228
TC5	473	232
TC6	426	183
TC7	402	159
TC8	438	196
TC9	394	151
TC10	512	272
TC11	370	126
TC12	354	110
TT1	2 470	2 278
TT2	2 800	2 616
TT3	3 400	3 231
TT10	2 400	2 206
Round 2		
TC1	1 322	1 101
TC2	1 174	950
TC3	1 157	932
TC5	906	675
TC6	920	690
TC7	985	756
TC10	923	693
TC12	977	748
TT1	1 687	1 475
TT2	1 950	1 745
TT3	2 070	1 868
TT5	1 860	1 653
TT6	2 180	1 981
TT7	1 610	1 397
TT9	2 180	1 981
TT10	1 630	1 417
TT12	2 010	1 806
Round 3		
TT2	1 563	1 348
TT3	1 075	848
TT5	1 383	1 164
TT6	1 357	1 137
TT7	1 144	919
TT9	1 632	1 419
TT12	1 450	1 233

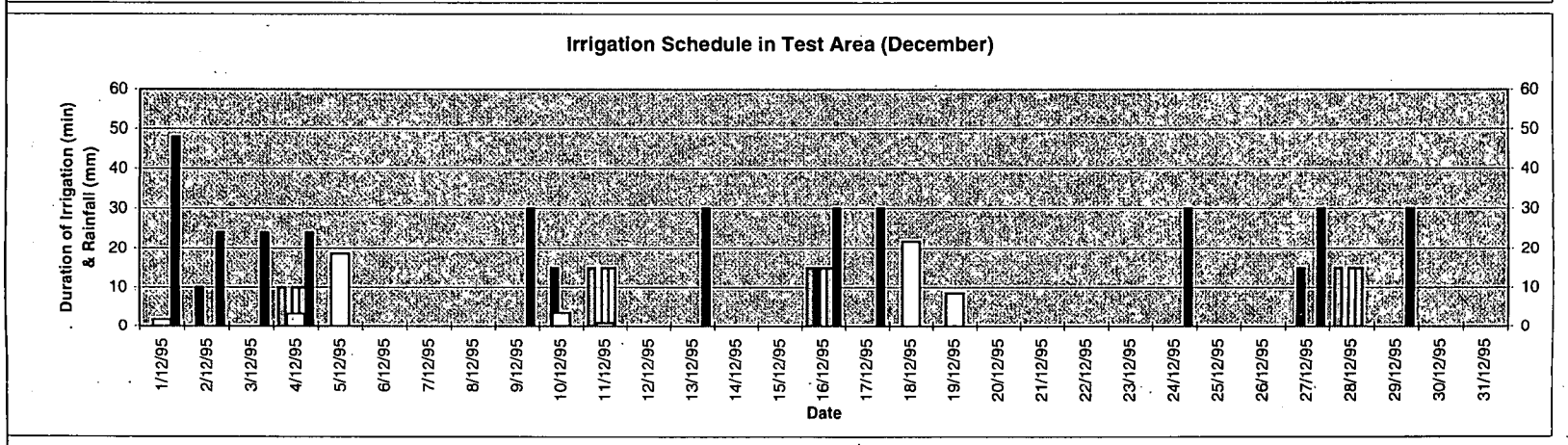


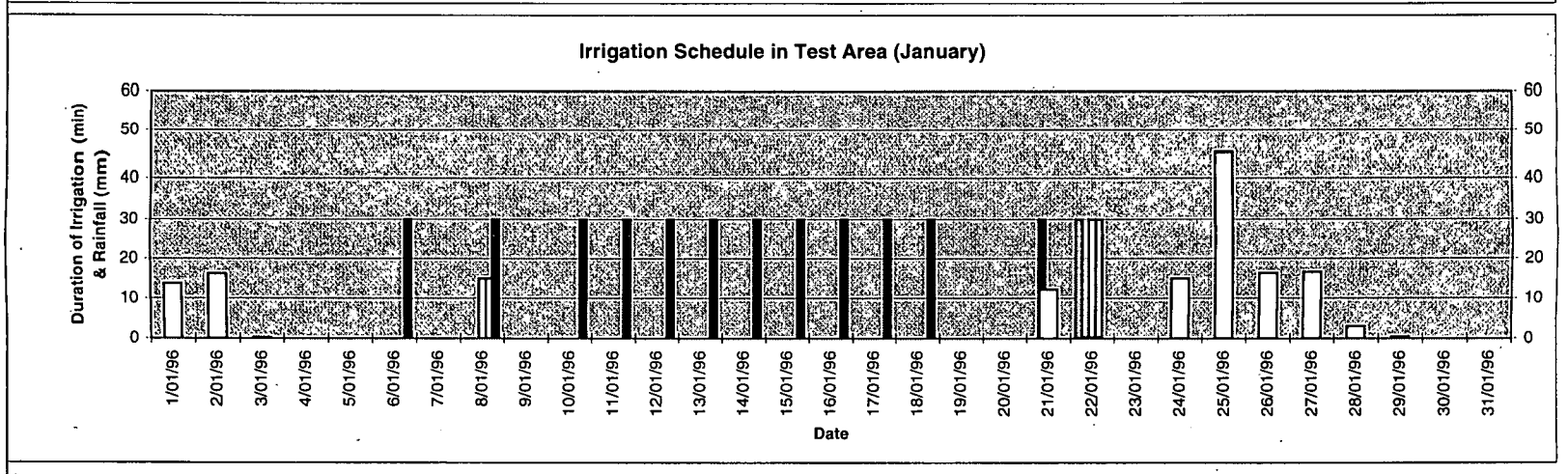
APPENDIX 6

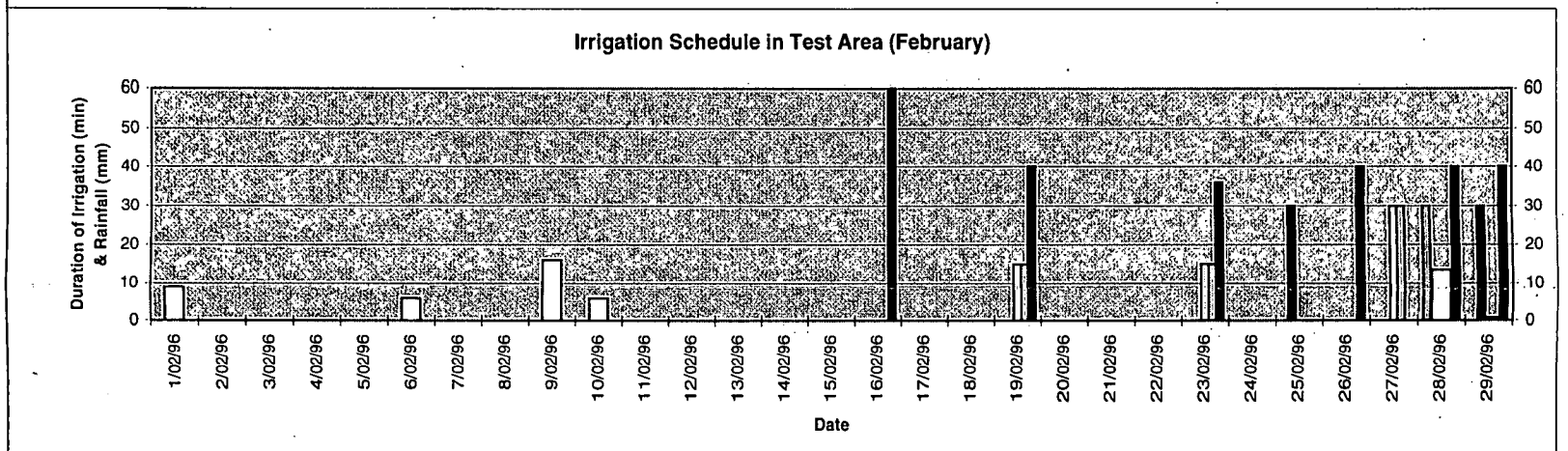
Irrigation and Rainfall Schedule in the Test Area

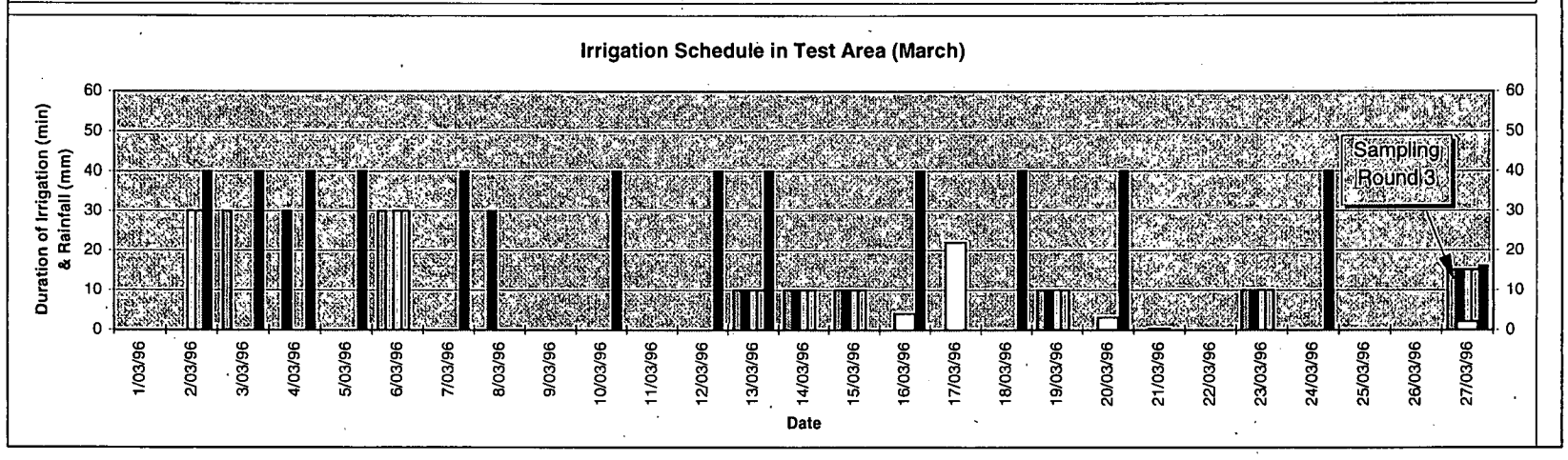












t-Test for Soil Moisture Comparison Between Rounds and Between All Control and Effluent-Affected Samples

Round 1	Round 2	Round 3
Contol		
Soil Moisture (dry basis) (%)	Soil Moisture (dry basis) (%)	Soil Moisture (dry basis) (%)
51.7	49.3	45.4
51.2	43.3	20.2
56.3	36.8	40.5
56.7	20.7	20.4
85.7	71.7	37.5
80.7	91.3	62.7
58.8	48.1	26.0
192.3	192.1	110.9
52.9	19.8	26.8
Effluent-affected		
50.4	44.8	24.1
62.7	35.1	25.6
56.6	42.1	36.7
48.2	20.4	28.4
76.2	68.4	34.1
136.6	102.7	52.8
49.8	73.1	30.6
168.0	174.9	148.7
42.2	20.1	23.3

t-Test: Paired Two Sample for Means

All rounds

	Contol	*Effluent-affected*
Mean	61.107	62.09997
Variance	1949.619	2029.612
Observations	27	27
Pearson Correlation	0.927791	
Hypothesized Mean Difference	0	
df	26	
t Stat	-0.30399	
P(T<=t) one-tail	**0.381778**	
t Critical one-tail	1.705616	
P(T<=t) two-tail	0.763555	
t Critical two-tail	2.055531	

t-Test: Paired Two Sample for Means

Control samples used

	Round 1	*Round 2*
Mean	76.25556	63.67954
Variance	2054.605	2834.528
Observations	9	9
Pearson Correlation	0.965368	
Hypothesized Mean Difference	0	
df	8	
t Stat	2.488998	
P(T<=t) one-tail	**0.01879**	
t Critical one-tail	1.859548	
P(T<=t) two-tail	0.037581	
t Critical two-tail	2.306006	

t-Test: Paired Two Sample for Means

Control samples used

	Round 2	*Round 3*
Mean	63.67954	43.3859
Variance	2834.528	828.2268
Observations	9	9
Pearson Correlation	0.951879	
Hypothesized Mean Difference	0	
df	8	
t Stat	2.229278	
P(T<=t) one-tail	**0.02818**	
t Critical one-tail	1.859548	
P(T<=t) two-tail	0.05636	
t Critical two-tail	2.306006	

Appendix 8

Calculation of estimated FC concentration on turfgrass based on depth of irrigant applied.

This calculation was perform to predict the concentration of FC on the turfgrass when the FC concentration in the irrigant and the amount of irrigant applied are known. Knowing the expected amount of FC on the turfgrass helped to determine why so little contamination was detected in the turfgrass samples from Round 2.

Irrigant was collected into plastic 2 L ice cream containers and then poured into 71 mm diameter bunzl jars. For the second sampling round, the depth of irrigant in the bunzl jar, H, was measured outside the clear jar (too avoid contaminating the sample). H varied from 18–28 mm (ignoring the smaller amount taken for membrane filtering. The ice cream containers had a 13×13 cm base. From this the depth, h, in the containers is calculated as follows:

$$h = H \times \frac{\pi \times 7.1^2}{4 \times 13^2} = 0.234H$$

Therefore for Round 2, $4.2 \leq h \leq 6.6$ mm.

Now, $B = \frac{C_B . h}{1000}$ where B is the number of FC deposited per cm^2, C_B is the concentration of FC per 100 mL of irrigant.

For a typical holding pond FC concentration of 1 000 cfu/100 mL the resulting concentration of FC of turfgrass is $4.2 \leq B \leq 6.6$ cfu/cm^2.

Therefore detection of FC in the turfgrass is much more difficult than it is in the irrigant itself.

Appendix 9

Calculation of turfgrass FC/*E. coli* per 100 mL equivalent.

Due to the nature of sampling, the concentration of FC in turfgrass in Round 3 was based on the surface area of the turfgrass, ie, FC per cm^2. This presents a problem in that it is difficult to compare these results with the original holding pond and irrigant FC levels since they are expressed in the different units of FC per 100 mL of water. As a consequence it was deemed more appropriate to convert concentration per square surface area to volume of irrigant applied so the results could be standardised for ease of comparison. The only additional parameter that was needed was the amount of irrigant applied.

At the time, this situation was not foreseen and so no measurements of the depth of irrigant applied were taken during Round 3. The other option was to use the measurements taken in Round 2. Therefore, the equivalent wetted area, $WA_{100,}$ to which 100 mL of irrigant is applied is expressed as:

$$WA_{100} = \frac{1000}{h} \quad \text{(Eqn 1)}$$

where WA_{100} is measured in cm^2 and h is measured in mm.

The actual size of the sample taken was 87 cm^2 and so the FC concentration was initially expressed in terms of cfu/87 cm^2. To convert cfu/87 cm^2 to cfu/100 mL eq the former must be multiplied by the ratio:

$$CF = \frac{WA_{100}}{87} \quad \text{(Eqn 2)}$$

Therefore,

$$\text{FC/100 mL eq} = \text{CF} \times \text{FC/87 cm}^2 = \frac{1000}{87h} \times \text{FC/87 cm}^2 \qquad \text{(Eqn 3)}$$

By substituting for known values of h and FC/87 cm^2, FC/100 mL eq can be determined.

In order to be able to use the h values for Round 2 the amount of irrigant applied must be the same for both rounds. One complicating factor for the fairways was that for Round 2, only one irrigator was operating at a time and for Round 3, three irrigators were operating simultaneously. This could mean that the flow rate, Q, per sprinkler

may not be the same under each circumstance and thus the amount applied would be different. To deal with this problem, Q for both rounds must be determined.

By knowing the pump pressure for both scenarios, the pipe friction losses and the nozzle resistance of the sprinklers, the flow rate could be determined for each round. A test was run on the supply pump and the supply pressures were as follows:

P_0 = 110 psi

P_1 = 109 psi = 751 kPa

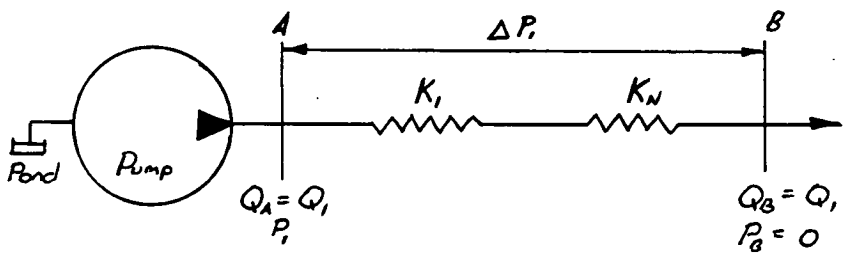
P_3 = 105 psi = 723 kPa

Where P_n is the pump static pressure and n refers to the number of irrigators operating simultaneously.

To calculate Q_n the irrigation system can be treated like an electric circuit where pressure ≡ voltage; flow rate ≡ amps and pipe friction, K_n and nozzle resistance, K_N ≡ electrical resistance. Based on Bernoulli's equation (Douglas et al. 1979: 380–381) pressure drop across a system is,

$$\Delta P \propto Q^2$$
$$\text{or } \Delta P = KQ^2 \qquad \text{(Eqn 4)}$$

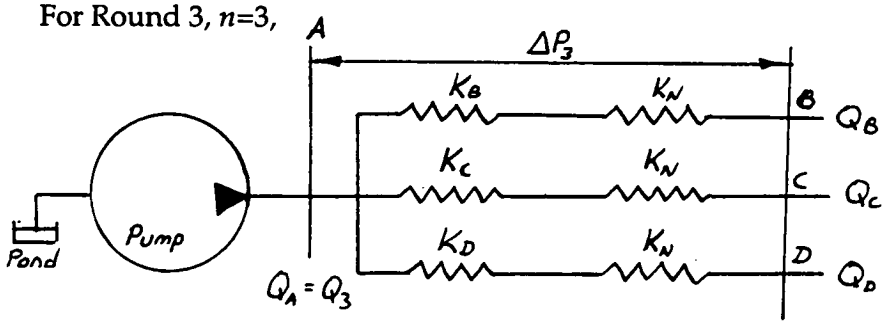
For Round 2, n=1



Here $\Delta P_1 = (K_1 + K_N)Q_1^2$ (Eqn 4.1)

It is assumed resistance due to pipe bends, joints and valves are negligible.

For Round 3, n=3,



Conservation of mass, $Q_3 = Q_B + Q_C + Q_D$ (Eqn 5)

Pressure drop across three pipe branches must be the same where $P_B = P_C = P_D = 0$,

Therefore,

$$\Delta P_3 = (K_B + K_N)Q_B^2 = (K_C + K_N)Q_C^2 = (K_D + K_N)Q_D^2 \qquad \text{(Eqn 6)}$$

Now if pipes B, C, D are the same in diameter, distance and surface roughness then,

$K_B = K_C = K_D$,

therefore,

$Q_B = Q_C = Q_D = Q_3/3$, substituting Eqn 5 into Eqn 6,

$$Q_3 = \sqrt{\frac{P_3}{K_B + K_N}} + \sqrt{\frac{P_3}{K_C + K_N}} + \sqrt{\frac{P_3}{K_C + K_N}}$$

$$= 3\sqrt{\frac{P_3}{K_B + K_N}} \qquad \text{(Eqn 7)}$$

K_n can be calculated from the nozzle performance chart supplied by the manufacturer for the Toro-674 series sprinklers. This information was converted into a nozzle performance chart below. For the range of operating pump pressures (482–689 kPa) and for the 72 size nozzle used on the course, K_n was relatively constant at a value of K_n= 53.1 kPa.s^2/L^2.

Pipe friction losses can be calculated using Darcy's pipe friction loss equation and a Moody chart. Head loss expressed in m is:

$$\Delta h = \frac{4fL}{d} \cdot \frac{\bar{v}}{2g}$$

or in terms of pressure

$$\Delta p = \rho g \Delta h = \frac{4fL}{d} \cdot \rho \frac{\bar{v}}{2} \qquad \text{(Eqn 8)}$$

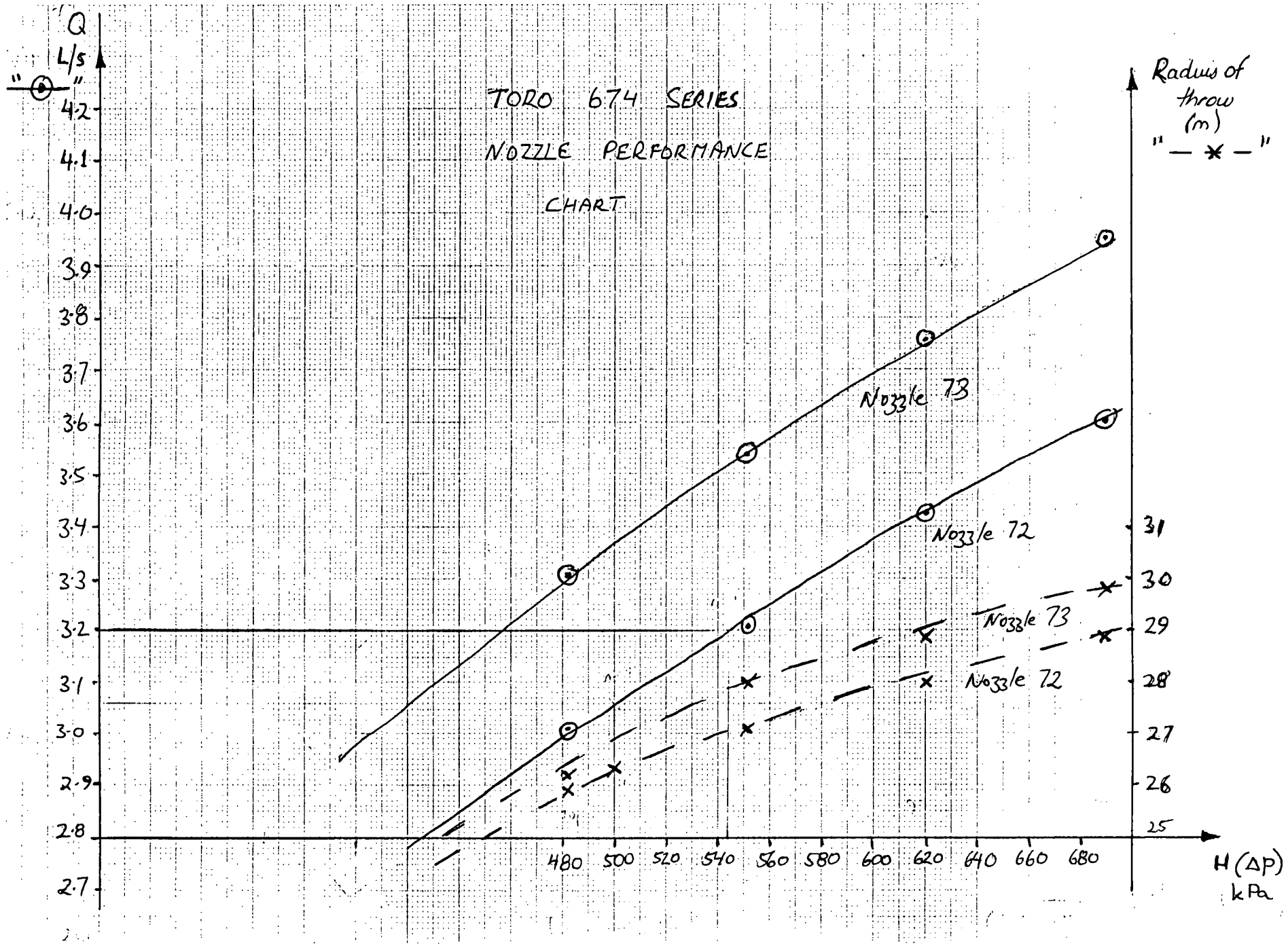
where f is the pipe friction factor based on the Reynolds number R_e and pipe roughness, k/d, d is the pipe diameter, v is the velocity of the effluent, g is acceleration due to gravity, L is the length of pipe estimated at 350 m, ρ is the density of water at ambient temperature.

From Eqn 4, $K_1 = \dfrac{\Delta P}{Q^2}$

$$= \frac{\rho g \Delta h}{Q_b^2}$$

Substituting Eqn 8 for Δh, $$= \frac{32\rho fL}{\pi^2 d^5}$$

$$= \frac{3.24\rho fL}{d^5} \qquad \text{(Eqn 9)}$$


TORO 674 SERIES
NOZZLE PERFORMANCE
CHART
Q
L/s
"⊙"
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
2.9
2.8
2.7
Radius of throw (m)
"— * —"
31
30
29
28
27
26
25
Nozzle 73
Nozzle 72
Nozzle 73
Nozzle 72
480
500
520
540
560
580
600
620
640
660
680
H (ΔP)
kPa

To calculated f we need to know the velocity of the flow. From anecdotal evidence Q_{pump}=720 L/min = 12×10^{-3} m^3/s when n = 4. Therefore, for n = 3, $Q_B = 3\times10^{-3}$ m^3/s. The size of the pipe is typically 50 mm diameter. The velocity is the ratio of the flow rate divided by the cross sectional area of the pipe calculated as follows:

$$\bar{v} = \frac{Q}{A} = \frac{3\times10^{-3}}{\frac{\pi}{4}0.05} = 1.53 \text{ m/s}$$

Now, $R_e = \frac{\rho \bar{v} d}{\mu} = \frac{\bar{v} d}{\nu}$, where, ν = kinematic viscosity, $\nu_{20^\circ C} = 1.007\times10^{-6}$ m^2/s

$$= \frac{1.53\times0.05}{1.007\times10^{-6}}$$

$$= 76{,}000$$

$f = \Phi(R_e, k/D)$ k for plastic piping is assumed similar to wrought steel = 0.046mm

$k/D = 0.046/50 \approx 0.001$

From the Moody chart, f = 0.006

Combining Eqn 7 and 9 and substituting for the above values,

$$Q_3 = 3\cdot\sqrt{\frac{P_3}{\frac{3.24\rho f L}{d^5} + K_N}} \quad \text{(Eqn 10)}$$

$$= 3\cdot\sqrt{\frac{723\times10^3}{\frac{3.24\times1000\times0.006\times350}{0.05^5} + 53.1\times10^9}}$$

$$= 9.23\times10^{-3} \text{ m}^3/\text{s}$$

$$= 9.23 \text{ L/s}$$

$$\therefore Q_B = 3.11 \text{ L/s}$$

Reiterating again based on the new value for Q_B,

$\bar{v}$ = 1.58 m/s, R_e = 78000, $f \cong 0.0058$

$\therefore$ ***Q_3 = 9.18 L/s = 551 L/min***

$\therefore$ ***Q_B = 3.06 L/s***

For Round 2 the same procedure is performed to check if $Q_1 = Q_B$ for Round 3,

$P_1 = 109$ psi $= 751$ kPa,

From Eqn 4.1,

$$Q_1 = \sqrt{\frac{P_1}{K_1 + K_N}}$$

Calculating K_1 by assuming $Q_1 = 4$ L / s

$\therefore \overline{v_1} = 2.0$ m / s, $R_e = 101\,000$, $k/D = 0.001$, $f = 0.0056$

$$\therefore K_1 = \frac{3.25 \times 1000 \times 0.0056 \times 350}{0.05^5} = 2.04 \times 10^{10}$$

$$K_N = 5.31 \times 10^{10}$$

$$\therefore Q_1 = \sqrt{\frac{751 \times 10^3}{(2.04 + 5.31) \times 10^{10}}} = 3.20 \times 10^{-3} \text{ m}^3 / \text{s}$$

Reiterating using value of Q_1,

$\overline{v}_1 = 1.63$ m / s, $f = 0.0056$ again

$\therefore \boldsymbol{Q_1 = 3.2\ L / s \approx Q_B}$

Therefore since the amount of irrigant applied is about the same for both rounds then the h values for Round 2 can be used for Round 3.

The h, WA_{100}, CF and FC concentration values for the turfgrass for Round 3 are tabulated as follows:

Site	h (mm)	$WA100$ (cm^2)	CF	GC cfu/87 cm^2	GC cfu/100 mL eq	GT cfu/87 cm^2	GT cfu/100 mL eq
1	7.2	139	1.6	300	480	6 800	11 000
2	3.5	286	3.3	<10	<33	20	66
3	8.1	123	1.4	40	56	<100	<140
5	5.1	196	2.3	400	920	140	320
6	3.2	313	3.6	100	360	30	110
7	7.2	139	1.6	<100	<160	30	130
9	2.3	435	5.0	10	50	200	1 000
10	8.1	123	1.4	<10	<14	<100	<140
12	3.2	313	3.6	<10	<36	3 600	13 000

Appendix 10

BASIC EPIDEMIOLOGICAL FEATURES OF EXCRETED PATHOGENS BY ENVIRONMENTAL CATEGORY

Pathogen	Excreted load[a]	Latency[b]	Persistence[c]	Multiplication outside human host	Median infective dose (ID_{50})[d]	Significant immunity?	Major nonhuman reservoir?	Intermediate host
Category I								
Enteroviruses[e]	10^7	0	3 months	No	L	Yes	No	None
Hepatitis A virus	10^6(?)	0	?	No	L(?)	Yes	No	None
Rotavirus	10^6(?)	0	?	No	L(?)	Yes	No(?)	None
Balantidium coli	?	0	?	No	L(?)	No(?)	Yes	None
Entamoeba histolytica	10^5	0	25 days	No	L	No(?)	No	None
Giardia lamblia	10^5	0	25 days	No	L	No(?)	Yes	None
Enterobius vermicularis	Not usually found in faeces	0	7 days	No	L	No	No	None
Hymenolepis nana	?	0	1 month	No	L	Yes(?)	No(?)	None
Category II								
Campylobacter fetus ssp *jejuni*	10^7	0	7 days	Yes[f]	H(?)	?	Yes	None
Pathogenic *Escherichia coli*[g]	10^8	0	3 months	Yes	H	Yes(?)	No(?)	None
Salmonella								
S. typhi	10^9	0	2 months	Yes[f]	H	Yes	No	None
Other salmonellae	10^6	0	3 months	Yes[f]	H	No	Yes	None
Shigella spp	10^7	0	1 month	Yes[f]	M	No	No	None
Vibrio cholerae	10^7	0	1 month(?)	Yes	H	Yes(?)	No	None
Yersinia enterocolitica	10^6	0	3 months	Yes	H(?)	No	Yes	None
Category III								
Ascaris lumbricoides	10^4	10 days	1 year	No	L	No	No	None
Hookworms[h]	10^3	7 days	3 months	No	L	No	No	None
Strongyloides stercoralis	10	3 days	3 weeks (free-living stage much longer)	Yes	L	Yes	No	None
Trichuris trichiura	10^3	20 days	9 moths	No	L	No	No	None

Pathogen	Excreted load[a]	Latency[b]	Persistence[c]	Multiplication outside human host	Median infective dose (ID_{50})[d]	Significant immunity?	Major nonhuman reservoir?	Intermediate host
Category IV								
Taenia saginata and *T. solium*[i]	10^4	2 months	9 months	No	L	No	No	Cow (*T. saginata*) or pig (*T. solium*)
Category V								
Clonorchis sinensis[j]	10^2	6 weeks	Life of fish	Yes[k]	L	No	Yes	Snail and fish
Diphyllobothrium latum[j]	10^4	2 months	Life of fish	No	L	No	Yes	Copepod and fish
Fasciola hepatica[j]	?	2 months	4 months	Yes[k]	L	No	Yes	Snail and aquatic plant
Fasciolopsis buski[j]	10^3	2 months	?	Yes[k]	L	No	Yes	Snail and aquatic plant
Gastrodiscoides hominis[j]	?	2months(?)	?	Yes[k]	L	No	Yes	Snail and aquatic plant
Heterophyes heterophyes[j]	?	6 weeks	Life of fish	Yes[k]	L	No	Yes	Snail and fish
Metagonimus yokogawai[j]	?	6 weeks(?)	Life of fish	Yes[k]	L	No	Yes	Snail and fish
Paragonimus westermani[j]	?	4 months	Life of crab	Yes[k]	L	No	Yes	Snail and crab or crayfish
Schistosoma								
S. haematobium[j]	4 per millilitre of urine	5 weeks	2 days	Yes[k]	L	Yes	No	Snail
S. japonicum[j]	40	7 weeks	2 days	Yes[k]	L	Yes	Yes	Snail
S. mansoni[j]	40	4 weeks	2 days	Yes[k]	L	?	No	Snail
Leptospira spp	urine(?)	0	7 days	No	L	Yes(?)	Yes	None

Source: Feachem, F. G. et al. *Sanitation and disease: health aspects of excreta and wastewater management.* Chichester, John Wiley, 1983. Reprinted by permission of the World Bank.

[a] Typical average number of organisms per gram of faeces (except of *Schistosoma haematobium* and *Leptospira* species, which occur in urine).

[b] Typical minimum time from excretion to infectivity.

[c] Estimated maximum life of infective stage at 20–30°C.

[d] L Low ($< 10^5$); M medium ($\approx 10^6$); H high ($> 10^6$); ? uncertain.

[e] Includes polio-, echo-, and coxsackieviruses.

[f] Multiplication takes place predominantly on food.

[g] Includes enterotoxigenic, enteroinvasive, and enteropathogenic *E. coli.*

[h] *Ancylostoma duodenale* and *Necator americanus.*

[i] Latency is minimum time from excretion by man to potential reinfection of man. Persistence here refers to maximum survival time of final infective stage. Life cycle involves one intermediate host.

[j] Latency and persistence as for *Taenia* species. Life cycle involves two intermediate hosts.

[k] Multiplication takes place in intermediate snail host.

Type of reuse	Level of treatment	Reclaimed water quality [1]	Reclaimed water monitoring [2]	Controls
INDIRECT POTABLE				
Surface water	Secondary		pH weekly	State Statutory requirements met. Surface water should comply with raw drinking water guidelines beyond mixing zone. (Appendix 1)
	Pathogen reduction[5]	Thermotolerant coliforms [3] <1000org/100ml[4]	Thermotolerant coliforms[3] weekly Disinfection systems daily[6]	Subsequent treatment to drinking water guidelines by filtration and additional treatment (Appendix 1)
Groundwater				
Recharge by spreading into potable aquifer recharge area	Secondary, possible need of Pathogen reduction[5], Filtration and/or Advanced treatment (site specific)	Site specific, No deleterious effects on aquifer water quality	pH weekly	Minimum 3 m depth to groundwater. Minimum retention time of reclaimed water underground prior to withdrawal, 12 months. Groundwater should comply with raw drinking water guidelines after mixing. (Appendix 1)
Recharge by injection into potable aquifer recharge area	Secondary + Filtration,	No deleterious effects on aquifer water quality	pH weekly	Minimum retention time of reclaimed water underground prior to withdrawal, 12 months. Groundwater should comply with raw drinking water guidelines after mixing. (Appendix 1)
	Pathogen reduction[5], Advanced treatment may be required. Site specific.	Thermotolerant coliforms[3] <1000org/100ml[4]	Thermotolerant coliforms[3] weekly Disinfection systems daily[6]	

Type of reuse	Level of treatment	Reclaimed water quality[1]	Reclaimed water monitoring [2]	Controls
URBAN (NON POTABLE) **Residential** Garden watering Toilet flushing Car washing Path/wall washing	Secondary + Filtration, Pathogen reduction[5]	pH 6.5 - 8.0[7] ≤2 NTU[8] 1 mg/l Cl_2 residual[9] after 30 min or equivalent indicator organism reduction to <10 thermotolerant coliforms[3]/100 ml[4]	pH weekly BOD weekly Turbidity continuous Disinfection systems daily[6] Thermotolerant coliforms[3] daily	Plumbing controls
Toilet flushing closed systems	Secondary + Filtration Pathogen reduction[5]	1 mg/l Cl_2 residual[9] or equivalent level of disinfection	Disinfection systems daily[6] Thermotolerant coliforms[3] weekly[6]	Plumbing controls. For non residential usage, legionella controls and biocide dosing may be required

Type of reuse	Level of treatment	Reclaimed water quality[1]	Reclaimed water monitoring [2]	Controls
URBAN (NON POTABLE)				
Municipal with uncontrolled public access				
Irrigation open spaces, parks, sportsgrounds	Secondary + Filtration	pH 6.5 - 8.0[7]	pH weekly BOD weekly	Nutrients, Toxicants and Salinity Controls,
Dust suppression, construction sites, mines		≤2 NTU[8]	Turbidity continuous	
Ornamental waterbodies	Pathogen reduction[5]	1 mg/l Cl_2 residual[9] or equivalent level of pathogen reduction	Disinfection systems daily[6]	Colour reduction may be necessary for ornamental uses
		<10 thermotolerant coliforms[3]/100ml[4]	With disinfection system e.g. Cl_2 thermotolerant coliforms[3] monthly[6]	
Municipal with controlled public access				
Irrigation open spaces, parks, sportsgrounds	Secondary,		pH weekly SS weekly	Irrigation during times of no public access. Withholding period 4 hours or until irrigated area is dry.
Dust suppression, construction sites, mines	Pathogen reduction[5]	<1000 thermotolerant coliforms[3]/100ml[4]	Disinfection systems daily[6] Thermotolerant coliforms[3] weekly	

Type of reuse	Level of treatment	Reclaimed water quality[1]	Reclaimed water monitoring [2]	Controls
AGRICULTURAL **Food production** Crops in direct contact with reclaimed water e.g. via sprays	Secondary + Filtration, Pathogen reduction[5]	pH 6.5 - 8.0[7] ≤2 NTU[8] 1 mg/l Cl_2 residual[9] or equivalent level of disinfection <10 thermotolerant coliforms[3]/100ml[4]	pH weekly Turbidity continuous Disinfection systems daily[6] thermotolerant coliforms[3] monthly[6]	Nutrients, Toxicants and Salinity Controls,
Crops not in direct contact with reclaimed water e.g. via flood or furrow irrigation	Secondary, Pathogen reduction[5]	<1000 thermotolerant coliforms[3]/100ml[4]	pH weekly BOD weekly SS weekly Thermotolerant coliforms[3] weekly	Separation of edible product from contact with water Flood or furrow irrigation only Nutrients, Toxicants and Salinity Controls
Crops sold to consumers cooked or processed which cannot be diverted to other uses	Secondary, Pathogen reduction[5]	pH 6.5 - 8.0[7] <1000 thermotolerant coliforms[3]/100ml[4]	pH weekly SS weekly Thermotolerant coliforms[3] weekly Disinfection systems daily[6]	Nutrients, Toxicants and Salinity Controls

Type of reuse	Level of treatment	Reclaimed water quality[1]	Reclaimed water monitoring [2]	Controls
Aquaculture				
Non-human food chain	Secondary	<10,000 thermotolerant coliforms[3]/100ml[4]	pH weekly SS weekly Thermotolerant coliforms[3] weekly	Nutrients, Toxicants and Salinity Controls TDS <1000mg/l
	Maturation ponds (5 days retention time), Pathogen reduction[5]		Disinfection systems daily[6]	<10% change Turbidity (seasonal mean conc.) Dissolved oxygen controls may be required for fish, zooplankton
Human food chain	Secondary + Filtration Pathogen reduction[5]	pH 6.5 - 8.0[7] ≤2 NTU[8] 1 mg/l Cl_2 residual[9] or equivalent level of disinfection <10 thermotolerant coliforms [3]/100ml[4]	pH weekly Turbidity continuous Disinfection systems daily[6] Thermotolerant coliforms[3] weekly	Nutrients, Toxicants and Salinity Controls, Depuration of filter feeders required Dissolved oxygen controls may be required.
Silviculture, turf and non food crops	Secondary		pH weekly SS weekly	Restricted public access. Withholding period 4 hours

Type of reuse	Level of treatment	Reclaimed water quality[1]	Reclaimed water monitoring [2]	Controls
Pasture and fodder Horticulture	Secondary	<1000 thermotolerant coliforms[3]/100ml[4]	pH weekly SS weekly Thermotolerant coliforms[3] weekly Disinfection systems daily[6]	Nutrients, Toxicants and Salinity Controls, Beef measles controls
Pasture and fodder for dairy cattle	Secondary, Pathogen reduction[5]	pH 6.5 - 8.0[7] <200 thermotolerant coliforms[3]/100ml[4] <10 thermotolerant coliforms[3]/100ml[4]	pH weekly SS weekly Thermotolerant coliforms[3] weekly Disinfection systems daily[6]	Nutrients, Toxicants and Salinity Controls, Withholding period of 5 days No withholding period Beef measles controls

Type of reuse	Level of treatment	Reclaimed water quality[1]	Reclaimed water monitoring [2]	Controls
RECREATIONAL				
Primary contact recreation Swimming Diving Waterskiing Surfing Windsurfing	Secondary + Filtration, Pathogen reduction[5]	pH 6.5 - 8.0[7] <150 thermotolerant coliforms[3]/100ml[4]	pH weekly SS weekly Thermotolerant coliforms[3] weekly Disinfection systems daily[6]	Receiving water meets bathing water quality guidelines (NHMRC 1990) Surface films absent Nutrient controls No skin and eye irritating factors
Secondary contact recreation Boating Wading Fishing	Secondary, Pathogen reduction[5]	pH 6.5 - 8.0[7] <1000 thermotolerant coliforms[3]/100ml[4]	pH weekly SS weekly Thermotolerant coliforms[3] weekly Disinfection systems daily[6]	Receiving waters should reach secondary contact guidelines after mixing (NHMRC 1990) Surface films absent
Passive recreation Ornamental waterbodies	Secondary	<10,000 thermotolerant coliforms[3]/100ml[4]	pH weekly SS weekly Thermotolerant coliforms[3] daily Disinfection systems daily[6]	Surface films absent. Restrictions on access

Type of reuse	Level of treatment	Reclaimed water quality[1]	Reclaimed water monitoring [2]	Controls
ENVIRONMENTAL **Groundwater saline intrusion prevention**	Secondary Advanced treatment may be required	Site specific	Site specific depending on water quality requirement	Industrial Waste Control No deleterious effects on potable aquifers
Stream augmentation	Secondary, (Site specific) Pathogen reduction[5] (Site specific)	Site specific	Site specific depending on water quality requirement	Receiving water quality requirements to be considered. State EPA regulations apply Temperature controls
INDUSTRIAL **Closed system**	Process specific	Site specific	Site specific depending on water quality requirement and end use	Additional treatment by user to prevent scaling, corrosion, biological growth, fouling and foaming
Open system **Human contact possible**	Secondary, Pathogen reduction[5]	Site specific <1000 thermotolerant coliforms[3]/100ml[4]	pH weekly, BOD weekly, SS weekly Thermotolerant coliforms[3] weekly Disinfection systems daily[6]	Windblown spray minimised; Additional treatment by user to prevent scaling, corrosion, biological growth, fouling and foaming

NOTES

1 Reclaimed water quality refers to the quality of water following treatment appropriate for a particular application and prior to mixing with the receiving waters.

2 This refers to monitoring which is additional to and separate from monitoring which is required for environmental compliance and process control. Monitoring takes place at the point of supply rather than at the treatment plant. In most cases this will be the point of entry to the reclaimed water reticulation system.

3 Thermotolerant coliforms. Refer to definitions.

4 Median value. Refer to main text.

5 Pathogen reduction beyond secondary treatment may be accomplished by disinfection e.g. chlorine, or by detention e.g. ponds or lagoons. Systems using detention only do not provide reduction of thermotolerant coliform counts to <10 per 100ml and are unsuitable as the sole means of pathogen reduction for high contact uses.

6 Disinfection systems refers to chlorination, ultraviolet irradiation or other disinfection systems. Monitoring requirements include such measures as checking chlorine residual or operational checking of uv equipment. Monitoring frequencies do not apply to pond or lagoon systems.

7 90% compliance for samples.

8 Limit met prior to disinfection. 24 hour mean value. 5 NTU maximum value not to be exceeded.

9 Residual after 30 minutes. Minimum value.